ELEMENTS OF GLASS-BLOWING

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TO

MY BROTHERS

PREFACE

In writing this book my aim has been to present the junior student as well as the inexperienced research worker in the laboratory with a concise and connected account of the systematic methods to be followed for success in glass-blowing. In preference to dealing with the details of manipulation for a number of individual pieces of apparatus, I have confined myself to the various processes classified under distinct heads, with typical examples illustrating them. With the help of the directions given under these headings, one ought to be able to devise a combination of some of them suited to one's own individual needs and skill. In cases where professional methods are unsuited to the limited skill of the average laboratory experimenter, alternative methods are suggested. In order to ensure that the diagrams shall be explanatory of the text, they have all been specially prepared by myself. A few abbreviations have been used in them. Where a piece is to be handled in a particular orientation by the hands, the left and right are indicated by the letters L and R, and generally in all the diagrams the left and right hand ends correspond to the left and right hand side of the page. Where a tube is to be cut, this is indicated by a full line (|),

while a dotted line (.....) indicates a joint. Since the way in which the flame is directed against the glass controls the shape of the zone of glass softened, it is indicated wherever necessary by short arrows (↗). Skill in glass-blowing is necessarily a result of long practice on the right lines, and, above all, the one thing to be avoided is undue haste in the manipulations.

I must thank Prof. A. W. Porter, D.Sc., F.R.S., for much valuable criticism in the preparation of this work for the press.

H. P. W.

UNIVERSITY COLLEGE,
LONDON, *January* 1923

CONTENTS

CHAPTER I

PRELIMINARY CONSIDERATIONS

CHAPTER II

CUTTING AND BENDING OF TUBES

CHAPTER III

JOINING TUBES

CHAPTER IV

BLOWING BULBS

CHAPTER V

ENCLOSED WORK

CHAPTER VI

CHAPTER VII

ELEMENTS OF GLASS-BLOWING

CHAPTER I

PRELIMINARY CONSIDERATIONS

Introductory.

A moderate knowledge and experience of the operations of glass-blowing are of invaluable help in modern experimental work, and as its importance cannot be over-emphasised, it is to be regretted that it has not yet found a permanent place in the curriculum. This knowledge is very useful to the average student, as it enables him to set up his own apparatus and effect minor repairs. To the research student it becomes an absolute necessity. How many times has a promising piece of research had to be postponed for want of some training in glass-blowing, and how often have inefficient substitutes and dodges had to be resorted to! This training is still more important (1) to workers in out-of-the-way stations and laboratories; (2) in times of political trouble, when supplies of ready-made apparatus are not available; and (3) in modern high vacuum work, where practically the whole of the apparatus is in glass.

As in any other art, skill in glass-blowing is the outcome of long practice combined with the knowledge of many important practical rules to be adhered to if time

is to be saved, and a maximum of personal convenience and comfort for work are to be obtained.

The standpoint adopted here not being that of the professional glass-blower, but of the laboratory student, a short description of the necessary implements will not be amiss.

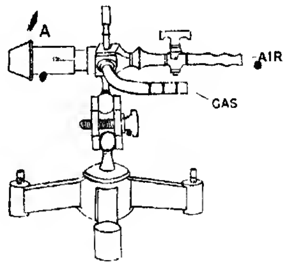
A separate steady table about 3 feet high should be set apart for this use, and its top surface preferably covered with some non-combustible material, such as asbestos board. It should be located in a comparatively dark corner of the laboratory, free from draughts and glaring illumination, so that the worker may always be able to make a proper judgment of the portion of glass heated, and the temperature it has attained from its colour. Since the usual professional practice is always to handle the longer and heavier part with the left hand, there should be some clear space beyond the table on the left-hand side of the worker.

Tools.

Beyond the usual bellows and blowpipe, the tools of the glass-blower are few and simple, since he relies more on his skill than on the tools to produce the desired results. Yet a few words about them may be of some advantage. The blowpipe largely used is of the Herapath type, and the one illustrated in Fig. 1, and obtainable of any dealer in scientific requisites, is provided with a multiplicity of adjustments, which is greatly in its favour. In addition to the adjustable cocks for the air and gas supply, it has also the different sizes of jets and the flexibility of a universal joint to produce the particular types of flame required in any direction according to the needs of the work in hand. In the use of this type of blowpipe care must be exercised to keep the air jet central and the external sleeve A' drawn out a few milli-

metres beyond the air nozzle to produce a quiet and hot blue flame.

A very simple and easily made blowpipe largely used by glass-blowers for professional work is the one shown



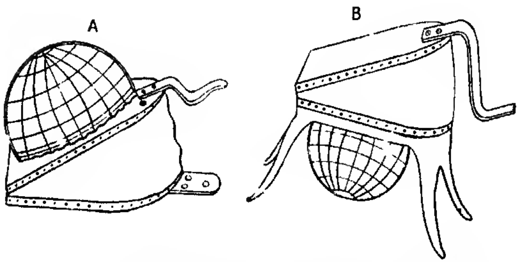


FIG. 1.—In bellows of the type A the rubber pressure chamber, being on the top, is readily accessible for repairs, though it has the drawback of exposing this sensitive portion to pieces of hot glass falling off the table. In the type B, though the pressure chamber is well protected from above, it is likely to be punctured by tips of glass projecting from the floor.

in Fig. 2. It is, in fact, a double blowpipe, composed of a small one mounted directly on top of a large one, the air jets for both being ordinary glass tubes fitted through a cork at one end. Centering screws are provided for the air-jet tube; and though between the two such a

compound blowpipe is capable of dealing with any job that demands a quick change from a large flame to a small one, additional variation is also provided in the form of a set of air-jet tubes of different sizes, fitted with corks ready at hand.

The Fletcher type of leather foot-bellows, as shown in Fig. 1, with air chamber of rubber protected by a net,

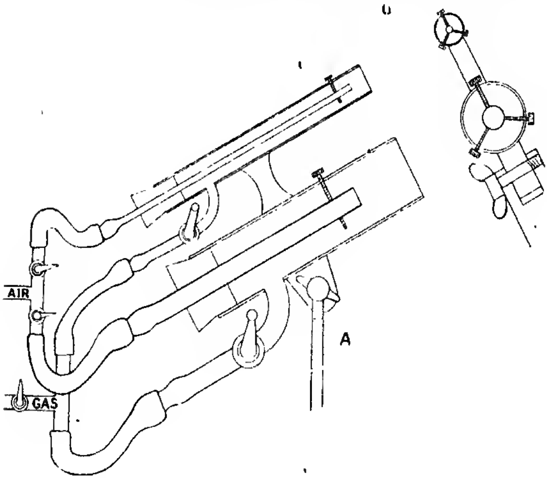


Fig. 2.

ensures a fairly steady blast of air when one has got accustomed to its use, and hence is widely popular. Professionals, however, prefer the larger and more elaborate semi-automatic types, with leather chambers that give a longer and steadier blast, without necessitating a too frequent kicking with the foot, with consequent shake, that may result in the deformation of the work in the flame. In addition to the extra control it allows over the flame, the small pair of bellows has also the

great advantage of easy portability, a necessary quality when an elaborate piece of apparatus is being assembled *in situ* on a research table. The many forms of motor-driven automatic blowers combine the advantages of both types, and are recommended if available.

The rest of the tools in frequent use are a small new triangular file, or, better, a hardened steel (glass) knife for cutting purposes, and a piece of arc-light carbon with

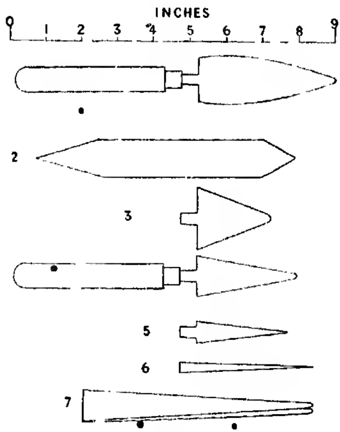


FIG. 3.

the end filed to form a cone ending in a blunt point, for use in enlarging the ends of narrow tubes. Professionals and experienced amateurs can spin glass in the flame, and they find very effective use for another tool made of a strip of stiff tapering metal sheet fixed on to a wooden handle as shown in Fig. 3. This type of tool is generally useful in three sizes as shown, and with them, the carbon cone can be entirely dispensed with. A few minor auxiliaries are also required occasionally, such as small

corks, and short pieces of rubber tube with one end closed by a bit of glass rod or tube. Professionals accustomed to quantitative work are able to arrange their procedure in such a way as to dispense with these accessories. It may be mentioned in this connection that it is better to avoid their use, and follow the procedure suggested later in the chapter, since thereby many chances of accidents leading to failures are eliminated.

A metre length of small-bore rubber tubing forms a very useful auxiliary for use in blowing through when working a large or complicated piece in the flame, that cannot be conveniently taken up to the mouth for blowing. In the choice of this tube, as well as in those used for air and gas connections, care must be exercised to select tubing with thicker walls than that commonly used in the laboratory for gas connections, and the harder and springy variety of rubber that is not too flexible is to be preferred.

This is to guard against the consequences, possibly damaging to the work, if accidentally the tubes get choked or squeezed at a critical stage of the operation. However, should such an accident happen, its consequences would be nullified if the worker takes care to have always at hand a small idle flame such as a burning candle, so that the blowpipe may be relit without delay, thus preventing the consequent cooling and cracking of the work. Some of these minor precautions are very profitable in the long run, and if systematically adopted would eliminate a great deal of failure and disappointment.

The management of the blowpipe to obtain the proper flames for the various stages of the work is a matter of some importance, and the beginner will do well to practise a little before starting on the work. The inner nozzle in the blowpipe is for air, and care must be taken

to see that it is connected properly to the air supply (bellows) and not by mistake to the gas supply, in which case the gas on lighting would be seen to burn as a small conical flame from the inner nozzle and not the outer as it should. Before the flame is lighted, the air nozzle should be adjusted quite central to the outer, and the outer sleeve pulled out so that its end is a few millimetres in front of the air nozzle, as shown in Fig. 2. When the gas is turned full on and lighted, a large smoky flame results, whose size can be adjusted by the amount of gas let in. If a little air is now turned on it will just project this flame forward and yet keep it fairly large and bright, and such a flame is very useful for warming up tubes before applying the hotter flame to them, and for gradual cooling or annealing after the work has been done in a hot flame.

When the air supply is increased still further, the flame becomes smaller, and turns bluish-grey in colour, getting very hot, since complete oxidation of the gas is taking place towards the tip of the flame. If the air nozzle is fine (1 mm. diameter), a pointed flame, Fig. 4 (B), of great heating power just inside the very tip is the result, and such a flame is very useful for local heating of small and narrow patches. If a wider nozzle and stronger blast are employed, a brush-shaped flame, as shown in Fig. 4 (D), of great heating power is the result, and is generally the one in use for softening larger masses of glass for blowing bulbs and working large joints. For average work an intermediate type of flame Fig. 4 (C) is obtained by so adjusting the air supply as to get a slightly noisy blue-grey flame with a small flicker of bright flame just at the base. The best-sized flame for average work is about 10 to 15 cm. long, with its largest diameter near the tip, equal to the diameter of the tube worked in the flame. By the relative adjustments of gas, air, and size

of nozzles, the size, shape, and character of the flame can be varied to a great extent; and in general the aim should be to use a flame of not too noisy a character, resulting from too strong a blast of air. For the strongest heating, the work should be placed just inside the tip of the flame and right in the middle of it, so that the flame may envelop the tube and heat it all round symmetrically.

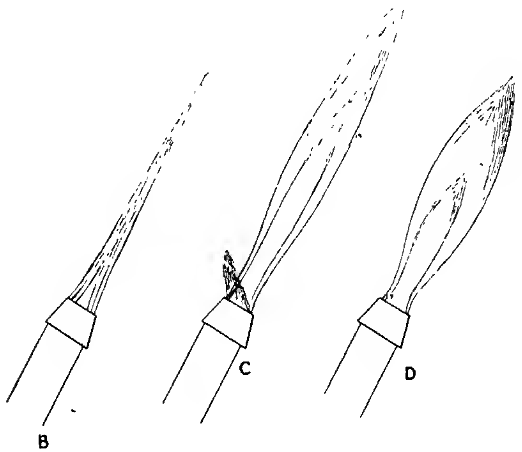


FIG. 4.

A very little practice will teach one the relative adjustments of gas and air necessary to secure the proper type and size of flame, as well as the regions of it that produce the greatest and most uniform heating of the glass. A big flame of low heating power is in general obtained by an excess of gas and less air through a wide nozzle, while a fine pointed hot flame of blue colour for small local heating is produced by a strong blast of excess of air through a fine nozzle with a diminished supply of gas.

Soft soda glass is almost universally used for blowing purposes in the laboratory, though the harder varieties of lead glass and combustion glasses, as well as the modern pyrex glass and quartz glass, find applications in high temperature work—the latter two varieties requiring the higher heat of the oxygas flame to fuse them. For general vacuum work, apparatus are generally improvised out of soft soda glass, because of its easy fusibility, though it is far more sensitive to imperfect workmanship. Since this variety of glass softens easily in the flame, it is advantageous to use, wherever possible, tubes with comparatively thick walls and wide bore, especially if the worker has not sufficient skill to manipulate the softened glass without serious deformation. On this ground, tubes 5 to 10 mm. bore with walls about a millimetre thick are the safest to use.

To be free from the contaminating influence of unknown impurities it is quite essential, especially for high vacuum work, to clean and dry the glass thoroughly before starting work on it; and in many cases it is an easier plan to clean the tubes themselves first rather than the finished apparatus afterwards. A handful of crystals of potassium dichromate shaken with some concentrated sulphuric acid forms a very active and effective cleansing reagent, the acid being entirely washed out afterwards by a liberal use of tap water and alternate brushings with a swab of cotton wool to dislodge sticking dust and dirt. The tube is washed free of tap water with distilled water, and drained dry in a vertical position, the open ends being plugged by cotton wool to exclude dust.

We will now proceed to discuss briefly some of the principles of operation in actual glass-blowing most suitable for the student in the laboratory, paying attention at the same time to the processes adopted by the

expert to secure reliability and beauty of the finished product. The expert secures this symmetry of good work by the adoption of a systematic and calculated procedure from the very beginning, and these are essential points that do not seem to have received adequate emphasis or attention in other works on the subject.

The first operation is that of taking the required length of tubing out of the usual 6 or 8 feet lengths supplied by the makers, which we have already submitted to a thorough cleaning and drying process. The beginner proceeds straightaway to cut the tube with a file or knife, but the expert employs a method which, though seemingly complicated, is undeniably the best. We will discuss it at some length, since it is of such fundamental importance.

Uniformity of thickness all round worked glass is essential, since in its absence the unequal strains set up on cooling invariably lead to fracture. With a stationary flame, this uniformity can be secured only by a uniform rotation of the tube in the flame. This cannot be properly done unless there is an axis round which to rotate the tube. Hence the expert starts his glass work by drawing this axis at the two ends of the piece he is going to work. The forming of this axis or spindle (about 6 inches in length) is by no means as easy as it looks. In addition to being stiff enough to bear the weight of the tube, when held by its stem in the left hand, as shown in Fig. 5, it has also to be quite axial to the tube to permit a rapid rotation without undue wobbling.

Though the rotation of the glass in the flame is effected by the twirling motion of the spindle between the thumb and forefinger of the left hand, the other end of the tube has to be suitably supported by the upturned forefinger and thumb of the right hand, and for this a spindle drawn out at this end of the tube is a great advantage.

Two such good spindles drawn out axially to the tube are useful also for closing or opening either end for blowing purposes, without having resource to corks, tubes, plugs, etc., which are liable to slip out or get burnt at the most awkward moment.

As a general rule, except when alternate blowing at either end is required in special pieces, the blowing is always done through the open end at the right hand side, while the left end is kept closed by a momentary application of the tip in the flame; it can be opened instantaneously, when required, by breaking off the extreme tip by a scratch. To be long enough for these purposes and to give a comfortable hold, the spindle should be not less than 6 inches in length. In addition to enabling a rapid rotation of the glass by a small rubbing motion of the fingers, the narrowness of these spindles serves also to make the rise of pressure inside gradual while blowing, and at the same time accidental blowing off of glass that is too soft by a momentary excess pressure is less likely to occur.

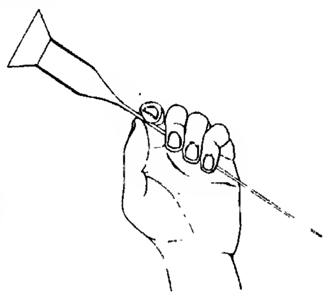


FIG. 5.—View from below.

Let us consider now the expert's way of drawing this all-important spindle, an operation he effects simultaneously while taking out the required length of tubing for his work. Let us suppose this is about a foot. He holds the tube in his left hand, allowing its weight to rest on the table in a V notch cut on its edge; and allows the flame to soften the glass at the very end of the

tube, rotation being imparted to the tube by the left hand fingers. When sufficiently softened, a waste piece of glass is stuck into this softened mass and drawn out to a 6-inch length, and the blob at the end melted off as indicated in Fig. 6 (1). This is a preliminary operation done simply to close this end of the tube. Incidentally it may be of interest to note that, though this spindle is fairly thick walled, it is comparatively flexible, because of the concavity of the shape at A in Fig. 6 (1), a thing to be avoided in drawing out the required length with the correct spindle from the other end of the tube as indicated below.

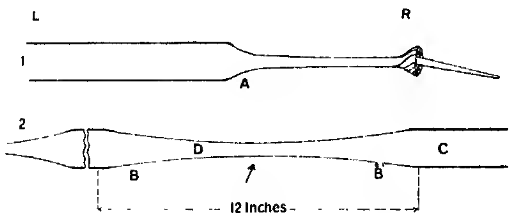


FIG. 6.

The tube is now reversed, end to end, and heated at a point a foot from the open upper end, until about 1 cm. length of the tube (in general a length equal to the diameter of the tube) is softened, particular care being taken not to get the softened portion into a screw in this operation. It is taken out of the flame and a puff of air blown in quickly through the open upper end in order to enlarge this softened portion to a bulb in diameter about one and a quarter times that of the tube. The two pieces are then immediately drawn apart, elongating this bulb to a length of about 12 inches ; meanwhile, the rotation of the tube is steadily kept up until the drawn-out stem has cooled down to rigidity. The shape obtained

by this procedure is conical, as shown at B in Fig. 6 (2), and though the walls are comparatively thin, the stem or spindle is rigid enough to take the weight of the glass without flexure. It is now melted off in the middle, and we get the required piece C with a 6-inch spindle attached to it at one end. While the required length has been cut off from the main tube by this process, we have another good spindle D formed already at the upper end of the longer tube ready for use in its turn. It will take some preliminary practice at this work before the spindle can be got quite axial, which is the primary desideratum. Any small residual eccentricity can easily be rectified by heating the spindle at B and doing a little of trial-and-error centering as with a lathe. Since the portions finally discarded as useless are only these spindles, it is easy to see how economical this procedure is, a factor of paramount importance in commercial operations.

The principal operations of glass-blowing may roughly be classified under five distinct heads, and any complicated apparatus can be made by a judicious combination of a few of these operations. We will discuss the details of these operations in the next few chapters, and endeavour to give under each the various aspects in which the job may present itself.

CHAPTER II

CUTTING AND BENDING OF TUBES

Though it is advisable to dispense with the cutting of glass (by knife or file) and apply instead the abovementioned drawing-off process, sometimes a cut has to be made, and this may be accomplished as follows:

At the place where the cut is to be made—this applies only to thin tubes less than a centimetre in diameter—a fine single scratch a few millimetres long (not all round the tube) is made with the help of a glass knife or a new triangular file. This scratch being kept turned upwards and a force exerted as if to bend the ends of the tube down, the two halves are pulled apart. The tube readily snaps at the mark, and if a single scratch has been made at right angles to the axes of the tube a sharp square cut is the result. If the tube does not snap easily, as is the case sometimes, the heated tip of a waste glass spindle of diameter less than a tenth of an inch rubbed gently along the scratch for a moment starts the crack, and the two halves may be pulled apart quite easily. In making a cut like this between two heavy halves, it is a wise precaution to have both the sides well supported, since the crack sometimes goes right round the tube instantaneously, permitting the two halves to fall apart.

For cutting tubes of a larger bore a simple procedure is to make a scratch, start a crack as above, and lead it right round carefully by the repeated applications of the hot point just in front of the crack. Though the small

irregularities of a cut made by this process disappear in the fire polishing, or by rubbing with carborundum paper, the following is the process professionally adopted to ensure clean square cuts:

A stout piece of iron wire, not less than an eighth of an inch in diameter and 15 inches in length, has one end bent round to form a smooth semicircle of a diameter equal to the external diameter of the tube to be cut, so that when this end is made red hot and applied to the tube it will be in contact with the glass as shown in Fig. 7. When the tube, after the preliminary small scratch, is laid horizontally on this hot wire and rapidly turned on its axis by the spindle, a crack flies right round the tube, giving a perfectly clean cut such as is required for joining the ends internally in the making of a liquid air Dewar tube of large bore.

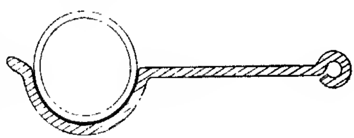


FIG. 7.

This method of cutting large tubes is only a particular aspect of the general procedure adopted in glass works for similar purposes, and it may be of some use to describe this procedure, as it is very convenient for cutting large bottles or other ware in the laboratory. A piece of diamond is employed to make the initial scratch, and the work is mounted centrally on a turn-table which is kept in slow rotation. A very small gas flame, not more than a tenth of an inch in size, suitably mounted on a stand, is adjusted to play against the rotating glass cylinder at the level of the scratch. In a few seconds a crack starting at the scratch flies right round the hot zone, giving a perfectly even cut.

There are occasions when a quick cut has to be made, as, for example, beyond a joint that has to be reheated when joining on a fresh tube to the cut end. The above-

mentioned processes are too slow for this purpose. In such a case an efficient method is simply to draw off the excess length of the tube by fusing it, and then, after the removal of the excess glass, to blow out a hole at this end. The edges of this hole, when fire polished after the removal of the films of glass adhering to them, give a fairly good square-cut end. Such an end may often be constricted a little, and hence may require to be enlarged to the full bore by the use of a charcoal cone or one of the spinning tools as described in a later chapter. If the end to be cut off is rather short and not more than a centimetre in diameter, an equally good—though somewhat daring—method is to make a sharp scratch and, resting the *diametrically opposite* part of the tube on the edge of the table, to give a sharp forward knock on the bit beyond the scratch with the wooden handle of one of the tools. It generally knocks the bit off, giving a sharp square cut, in the minimum of time.

It may happen that the cut is irregular, leaving a piece or two projecting out of the otherwise regular and square-cut end. This is specially annoying to the student, whose aim should be to make the end perfectly uniform before attempting a joint on to it. A rugged end of this nature can be easily made uniform by any one of the following methods. The projecting pips may be ground off on a carborundum paper or wheel, but a much less complicated way is to chip away the corners by filing with the flat of the triangular file, the filing being done towards the axis of the tube, in a slanting direction. If the end of the tube is given a preliminary warming before the filing is commenced, the glass chips off readily in small fragments, and the chances of breaking away a huge chip and thus increasing the irregularity is minimised to a great extent. If there is only a single large projecting pip, it may as readily be softened in the flame and judiciously drawn off at the

end of a waste spindle of glass. Similarly, a small hollow in the edge may as easily be filled by glass from the softened end of a spindle before a tube is joined on to this end.

Bending of Tubes.

The guiding principle in this operation to ensure a smooth round bend is to soften lightly a length of tube equal to at least three times its own diameter for a right-angle bend. It is then an easy enough task to be accomplished in a flame wide enough for the purpose, whether it be a special fish-tail burner or only the blowpipe flame adjusted to give a large smoky flame. In the use of the latter, care must be taken to soften the glass uniformly and slowly. There are, however, two distinct ways of effecting this operation. The first one is practised with small-bore tubes of comparatively thick walls that do not collapse easily, when a length of tubing is *lightly* softened, enough to be gently and gradually forced to the required shape. This is evidently the method of the inexperienced. The second one is that of the professionals, and requires considerable skill and experience when attempted on tubes of thin wall and large bore. For a nice U-bend, a length of about five times the diameter of the tube has to be melted down and gathered to form an elongated thick bulb in the middle of the tube. After a strong heating the operator pulls this apart gently, at the same time bending the tube to the required shape and blowing in all the while to expand it to the diameter of the rest of the tube, all these operations being effected simultaneously before the glass loses its heat. Even then it may require local correction.

Spirals.

The making of spirals of glass tubing is a fascinating part of glass work. It demands but a very limited skill

on the part of the operator, since the tube employed is usually thick walled and hence possesses considerable rigidity, even when softened enough to permit of easy bending into a spiral shape in small sections. There are two methods, and in both of them a large length of the tubing must be softened by a large bright flame. This must be played along the length of the tube, to ensure a uniform softening for the graceful bending to the curve required.

The first method is a free-hand process. Requiring no extra mechanical assistance, it is largely used when slight irregularities of shape in the finished spiral are not of any consequence. A metre length of tube about 3 mm. in bore, with walls not less than 1 mm. thick, is the average size of tube employed for the purpose. One end is closed by drawing a small spindle. About 15 cm. from this end the tube is bent sharply at right angles (Fig. 8 (1)) and the short limb AB serves as a handle in line with the axes of the spiral to be formed. The longer piece BC is then bent towards the operator at a point D by another right angle, the distance BD being the radius of the spiral to be formed. We are now ready to bend the tube from D to C as the required spiral, holding AB slantingly in the left hand and resting C lightly on the palm (upturned) of the right hand, the flame playing along DC, as shown in Fig. 8 (2). During this operation, a backwards and forwards motion of DC along its axis ensures the heating of a longer length than that covered by the large flame, and a to-and-fro semi-rotary motion about DC, exerted by the left hand holding and swinging the arm AB, ensures a fairly uniform softening of the length of tube all round. When the length D*b* shows signs of yielding because of the softening, it is taken off the flame and (AB being kept vertical in the left hand and DC horizontal) a clock-wise twisting force

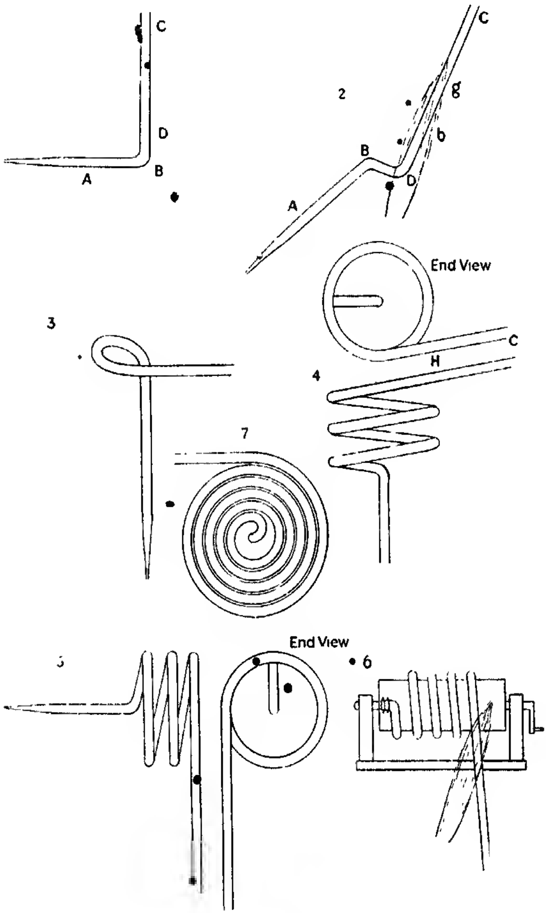


FIG. 8.

is exerted about the axes of AB. The bending of the tube D*b* under this strain is aided by a counter-clock-wise push of DC by the right hand. This forms a short sector of the circular bend for the first turn of the spiral, as indicated in Fig. 8 (3). It is presented to the flame again in position (2) and a further length *bg* softened and formed into a continuation of the arc of the circle previously formed. This operation is repeated until the required number of turns of the spiral have been formed. If the original length is found short, a fresh length may be joined on now and the work completed. After the first turn has been formed rather carefully, and made quite circular and axial to AB, the further turns are much easier, since we have only to see that the softened section of the tube is always bent into coincidence with the outline of the turn below it, when looked at axially, keeping of course the axial spacing between the successive turns by a normal or radial view. The straight portion HC of tube (4) must always be adjusted horizontal and in plane with the turn of the spiral just formed out of it, so that irregularities in the axial spacing may not arise. The winding of the spiral in this free-hand fashion has the great advantage that we can always have a good axial as well as radial view of the shape that is being formed, and thus rectify immediately any tendencies to irregularity.

Another free-hand process used by some experts is illustrated in (5), and here, instead of the spiral being wound up vertically, it is wound horizontally in one continuous operation, the softened region steadily winding up into a spiral and thus drawing a fresh portion of the tube into the flame. Since it is difficult to have a control over the radius of the turns everywhere from only a side view of it, the process is risky in practice and demands a higher degree of manipulative skill and eye judgment.

The second method requires mechanical aid and is practised when a true cylindrical shape and definite size are required with tubes of larger bore for the spiral. The tube is wound over a hollow drum of sheet iron or copper covered with sheet asbestos and horizontally pivoted with a winch handle at one end, as in Fig. 8 (6). If the edges of the metallic sheet forming the mandrel are overlapped, it can be reduced in diameter by squeezing it round, thus facilitating the withdrawal of the mandrel from the finished spiral. A bent end of the tube is tied to the mandrel by wire. The tube, as well as the region of the mandrel in the neighbourhood, is then heated by a large flame. As the tube softens, the winch is turned round slowly to wind the tube on and draw fresh portions into the flame.

Another useful type is the flat spiral of Fig. 8 (7). This is easily wound by the first free-hand process, the axial view permitting each turn to be adjusted in plane with the previous one and with a uniform separation from it.

Though not coming directly under the heading of this chapter, we may at this stage describe the procedures adopted to round or flatten the closed end of a tube. In either case the main principle is to remove the excess glass that accumulated while the tube was being closed by softening and drawing off the spindle. To round the right end of a tube A, for example, in Fig. 9 (1), heat it at *h* to draw off the spindle, when the glass will thicken and collapse down (2). This extra glass must be removed by repeated softening of this end and sticking the end of the spindle on to it and drawing it off; the drawn glass being wound on to itself while it is soft. Finally, shape (3) is secured for the end, where the wall is comparatively thin and nearly flat. After the small projecting pip *p* has been melted down, this end is softened by a flame (*r*) directed as indicated, and a gentle puff blown

in; the end then gets blown round like (4) and not into the shape (5), where it is larger than the diameter of the tube. If the end is to be flattened and not rounded, the heating is done largely on the end face alone of the tube by a flame (*f*) directed as shown, and after a gentle puff just enough to give the end a very slight bulge outwards (6), it is rubbed down flat while still soft by a few strokes with the flat blade of tool (4) of Fig. 3.

CHAPTER III

JOINING TUBES

Glass work is largely a question of joints, and the operations of joining can be roughly classified under eight different heads, whose salient points, including the precautions to be observed under each, are briefly considered below. The principal aim ought to be to work the glass at the joint so uniform in thickness with the walls of the tube on either side as to render the joint almost invisible. To achieve this end, the external diameter must also be made equal to that of the tube on either side by blowing out or drawing down. Half the trouble is over if the ends are cut quite square and of equal bore; and the two ends must be heated quite soft and uniform all round before they are put together. This latter operation must be done carefully and without undue haste, care being taken that they are in proper alignment, and that an all-round sealing contact of glass (without any holes) has been established. This is readily seen when a puff of air is blown in immediately to expand the accumulation of glass at the joint.

Since trouble is experienced at times in making a square cut by the usual methods, an alternative method is to blow out a hole after closing and rounding the end of the tube. Though this method is largely used, to get the hole of the correct size and shape (Fig. 9 (11)), is a matter requiring some experience. To do this, the closed end of the tube is rounded and then strongly

heated with a pointed flame so as to soften a circular region (at the end) equal to the diameter of the required

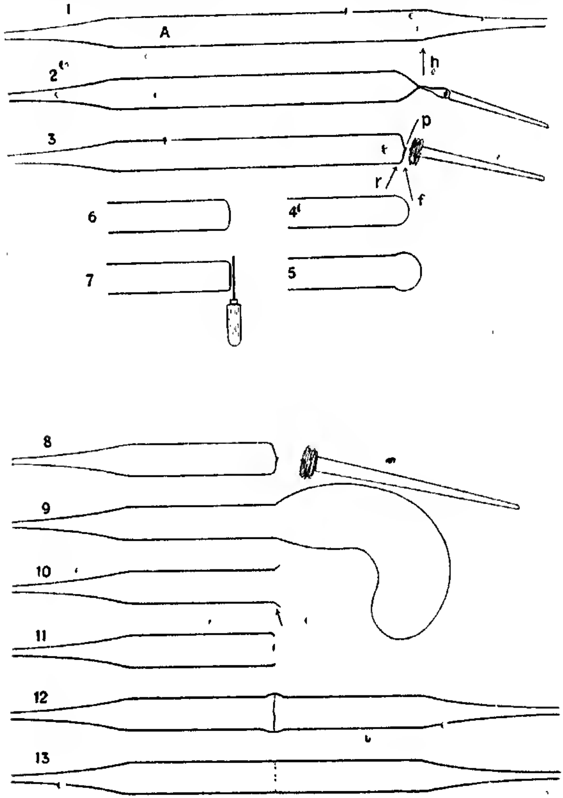


FIG. 9.

hole. A strong puff blows this off into a thin kidney-shaped film which is readily swept away by the knife, leaving the open end as shown in Fig. 9 (10). The minor

irregularities of the edges of this cut disappear when the end is softened, and by the concentration of the greater heating on the one or the other of the ends to be joined together, the openings can be made equal and thus to fit each other when they are put together.

Straight-line Joints—(1) *Equal Tubes.*

Three cases of this type usually occur in practice. The first is the joining of two short tubes of equal or very nearly equal bore, a simple enough job considering that it permits of easy rotation about the axial spindles at the ends of the tubes. The joint is softened down symmetrically all round, and after any small twist of the softened region has been carefully and immediately neutralised by a judicious turn of the one half relative to the other, it is gently blown out to form a small bulb as shown in Fig. 9 (12), and pulled apart (13) as the glass cools, so as to make the bore and thickness of glass in this region equal that of the tube. This operation is repeated over and over again until uniformity is secured at the joint. In cases where inconvenient lengths or shapes of glass or the lack of sufficient skill makes this plan impracticable, the beginner's course of going round the joint fusing patches by patches and blowing them out to the level of the tubes is the obvious one to follow. A point to be remembered in the adoption of the latter procedure is to employ only a small heating flame, while going round the joint rather slowly, thus allowing sufficient interval for cooling down before proceeding to heat the diametrically opposite region. In this way the joint does not get out of shape in inexperienced hands. The joining together of thick-walled tubes of capillary bore requires preliminary preparation of the ends, and is for convenience described under the third heading.

(2) *Unequal Tubes.*

The second case is when tubes to be joined are of unequal bore, as in a pipette; hence this may be called a pipette joint. The right end of the wider tube is drawn down to form a thick-walled short cone, and cut squarely off at a place where the thickness of wall and bore equal that of the smaller tube to be joined on to it. If the line of joint is arranged to lie exactly at the angle where the two tubes meet, the joint is rendered practically

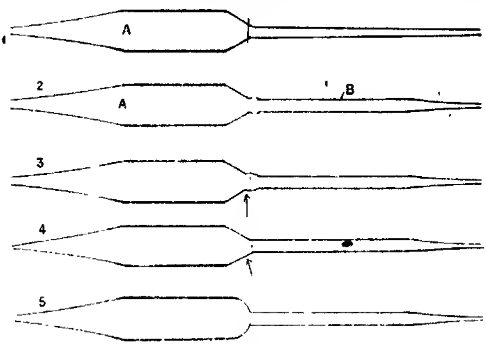


FIG. 10.

invisible; and since this is of fundamental importance in many of the subsequent operations, the procedure to be followed is illustrated in detail in Fig. 10, where A and B are the two pieces to be joined together. After putting the two heated ends together, the joint is worked out quite uniform as explained above, the heating being more on the side of the wide tube to ensure less risk of deformation at the joint. The narrower tube should be maintained to be of perfectly uniform bore and thickness right up to the joint beyond which the wider tube starts as a sharp cone. After this shape has been

secured (3) to the well-made joint, the conical portion of the wider tube is softened right up to the joint (4) and blown out slowly into a rounded hemispherical shape, a slight pressing together of the two halves during the final stage of this operation effectively counteracting any tendency to draw the two halves apart (5).

(3) *Capillary Tubes.*

The third case consists in joining tubes of great inequality in the thickness of the walls as well as in bore. A common example of this type is met with in making a Plucker discharge tube, where a millimetre bore capillary with thick walls has to be joined on to wide tubes of anything up to a centimetre or more in diameter. In such cases the end of the capillary tube has to be first fused and closed; then by blowing through the other end a small thick-walled bulb is formed as shown in Fig. 11. The outer semicircle of this is strongly heated and blown off, leaving at this end a short conical end of large bore with thick walls to which a glass of any size could be sealed on easily by the operations explained above. The wider tube side of the joint should be finally blown out hemispherical as indicated. A simpler case of this kind is the joining together of two pieces of capillary tubing. Heating the two square-cut ends and putting them together is too risky to be adopted generally, because of the liability of the narrow ends getting choked on softening or when put together improperly aligned. The safest course is to form the widened ends as described above and then join them together as a case of simple straight-line joint. The slightly wider bore which this operation is likely to leave at the joint can easily be eliminated, if required, by gathering up the glass on either side of the joint and blowing it into an elongated bulb of very thick walls, and then drawing it down

carefully to the diameter and bore of the rest of the tube.

Greater obstacles are encountered in dealing with thermometer tubes of very fine bore, since it is very difficult to blow through them, and inadvisable to do so, because of the difficulty of removing the moisture condensed inside the fine bore. The tendency of the fine

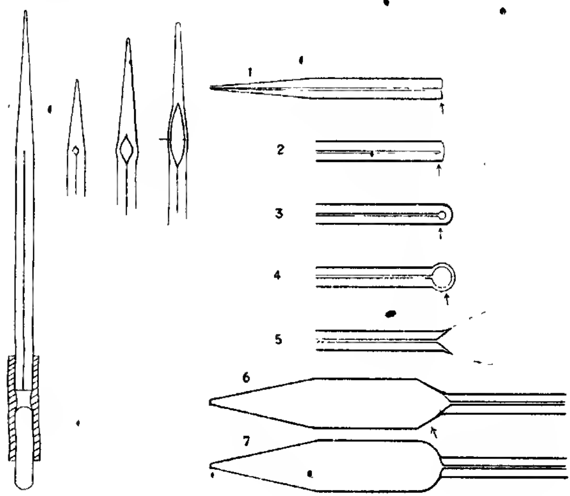


FIG. 11.

bore to get closed on the slightest softening can be effectively overcome by maintaining an air pressure inside while heating it, and by a careful manipulation this air pressure can be made to blow the bulb at the end, which is then drawn out into a short tube and cut to give the required end with large bore and thick walls. A very simple method of exerting the requisite pressure is to slip on the end of the thermometer tube a 2-inch

length of stout-walled pressure tubing as shown in Fig. 11, after closing the far end in the operation of drawing a spindle. The outer end of the rubber tube is plugged tightly by a bit of glass rod, and the compression of the enclosed air when the plug is pushed home exerts the requisite pressure, which may be increased still further by pinching the rubber tube. Professional practice differs from this, and is discussed at a later stage.

(4) *Angle Joints and T-pieces.*

Having got ready the pieces X and Y (Fig. 12), the first thing to do is to blow out a hole on the side of the tube X to which the piece Y is to be joined on. This hole should be of a slightly conical shape projecting out from the side of the tube and of a bore smaller than that of Y. This is because on heating, while the former tends to enlarge, the latter tends to contract under the capillary forces of the softened glass. If the side of the tube is simply heated to a bright red spot and blown out, there is risk of the hole being too large and elliptical, in addition to being formed flush with the tube as shown in Fig. 12 (1). This arises from our inability to heat a round spot of the correct size directly on the side of the tube. The right method of procedure is, first, to heat the spot to a dull red by a pointed flame, and then by sticking on to it the heated end of a waste spindle, to draw it out to a conical projection as in (2). The end region of this cone can now be heated properly to a disc of diameter less than the bore of Y, and blown out to give a hole of the proper shape and size (3). The edges of this hole as well as the tip of the tube Y are softened uniformly all round, care being taken to attain equality of bore of the two softened ends before they are put together, pressed in a little to ensure all-round sealing contact, and blown out slightly to expand the thick glass here. The beginner's

method is to blow through Y, and go round the joint patch by patch, taking care not to bulge out or thin the glass at the joint more than is required to ensure uniformity with the rest of the tube. The expert, on the other hand, rotates the joint in the flame backwards and forwards by a semicircle about the middle piece Y held horizontally in the left hand as an axis. When the

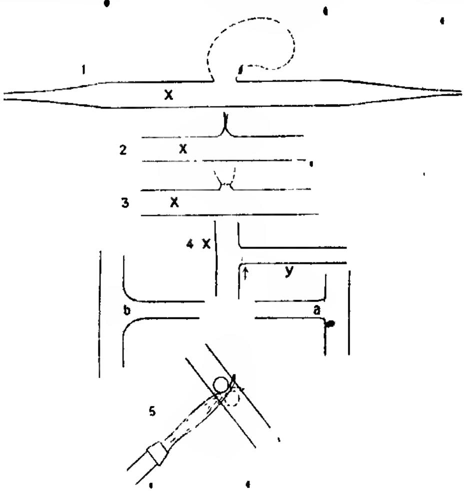


FIG. 12.

joint has thus become softened uniformly all round, by the use of a wider flame applied mainly on the side of the tube joined on, it is blown out a little, the side piece being kept vertical, with a gentle outward pull exerted by the right hand. Though this is the ideal procedure to obtain a good joint at a single heating, beginners are apt to come to trouble over it, and the following modification is recommended:

Employing not too sharp a flame and holding the

middle piece horizontally as for rotating the joint round it, play the flame on the joint and move the work up and down a little so as to make the flame graze alternately above and below the joint, as shown in Fig. 12 (5). The effect is to soften the front half of the joint, which may be gently blown out. Then rotate it by 180° and proceed with the other half similarly to complete the work. The aim in this class of work should be to achieve a thick-walled joint of the shape (*a*) rather than a thin-walled rounded type (*b*), and to secure this the joint should be heated more on the side of the tube joined on, and any tendency to pull the pieces apart carefully guarded against. Before annealing and cooling the work, the deformations due to the tube having got bent or out of plane during the work must be rectified by a judicious general heating.

(5) *Internal Joint.*

The internal joint, so called because it is located at the place where one tube passes through the walls of another, is of great application in high vacuum work, since by its liberal use leaking and troublesome joints of other types can be entirely dispensed with. Two types of this work arise in practice according as the smaller tube passes through the end or side of the wider tube, and the job can be satisfactorily done by either of the processes described under each.

In the first case, illustrated in Fig. 13, the right spindle of the wider tube A is melted off, and after the removal of the excess glass at the tip, the end is fused and blown to give a thick-walled hemispherical end. The central spot of this end is heated red and a cone pulled out as described above (2), and the whole of this conical projection softened and blown out to give a hole wider than the tube B to be slipped in. A narrow zone in the middle of tube B is softened all round and blown out a little, and

the two halves pressed together so as to form in B an enlargement as shown at C (4). The shape and size of this are of prime importance, and its angular edge should be quite circular and normal to the axes of the tube and of such a size as just to cover the hole at the end of A when slipped in (5). These two preparatory operations must be done in quick succession. Before the glass has cooled down, the pieces A and B are put together as in (5)

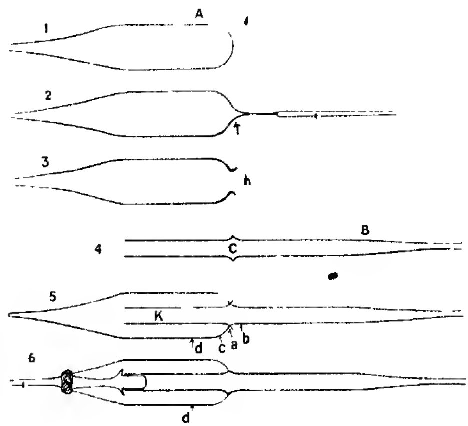


FIG. 13.

(after warming the edges), and a pointed flame applied as shown (*a*) to fuse together the line of contact. Then the pieces are pressed together a little to ensure that no holes are left at the joint. To work the joint uniform a larger flame is applied to the right side of the joint (*b*) and the work proceeded with as in the case of a line joint, only the left edge of the flame playing against the actual joint. The attempt should be to make the line of contact narrow, uniform, and circular, and the walls on either side

thick and slightly and gracefully curved, as shown. To get the line of joint narrow, which is essential the following procedure is found to be very useful in practice: The hole *h* at the end of the tube A is first blown larger than the bulb C. Then by the softening down of its edges which get thickened in the process, the hole is made small enough to fit C. If the joint is now proceeded with as before, probably because of the thickened edges of A coming into contact with the surface of C only along a very narrow line, the resulting line of joint is found to come out much narrower and hence better than usual. When the joint has been worked fine and smooth a broader flame is applied at *c* and the deformations as well as the thick glass walls here are blown out to a uniform hemisphere, an action assisted by pressing the two halves lightly together. If the glass has been kept in uniform rotation during the heating as well as blowing, the inner portion K of B keeps fairly central and axial, and by a slight softening of the tube at *d* any small defect in the centering of the inner tube is readily effected at this stage without deforming the joint in any way, and then B can be brought into axial alignment with K by softening it at *b*. A joint of this nature requires careful and prolonged annealing before being allowed to cool.

A modification to this procedure has to be adopted if the inner piece K is heavy and will not keep fairly central while the joint is being worked up. But in general, since we soften only one side of the joint at a time, *i.e.* (*b*) and then (*c*), the cooler glass of the other side provides a retaining support strong enough for the purpose, when the inner piece K is comparatively light and short. In cases where the piece K is heavy, or for any reason requires to be finished in a particular orientation, it is easy enough to arrange a proper support for this through the other end of A. A long waste spindle

stuck in through the left end and fixed in by a blob of sealing-wax as shown (6) is recommended for beginners.

The second case of internal joint is (1) shown in Fig. 14, where the downward bend of the smaller inner tube, in addition to its passage through the walls of the outer tube, adds extra complexity to the work. In such cases the general procedure is to have the inner and outer pieces (A and B) separate, and join them on either side of the walls of the bigger tube, blowing out the wall of

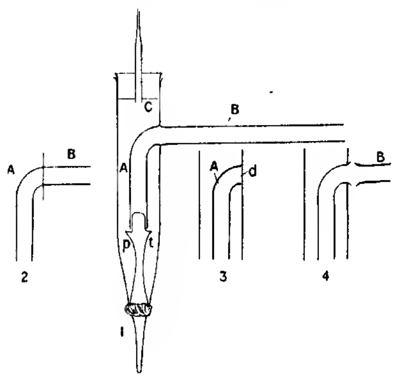


FIG. 14.

glass between them during the operations, and thus obtaining through communication. The inner tube is first bent (2) and cut to give the two pieces A and B. A good central support for the inner piece A is provided as described in the last section, with retaining prongs *p* and *t* for accurate work, and the piece A slipped into position through the wide end of C, which is then either drawn down to a spindle or closed by a cork with a central tube for blowing. The bent end of A is arranged to be almost in contact with the walls of C (3), and a

large spot *d* opposite the end of A is softened to a flat disc and permitted to establish all-round sealing contact with the end of A. After this joint is well worked by repeated heating and blowing, the central region *d* is blown off to give an opening on to which the piece B is sealed on as in making a T-piece (4). Since the heating and working are practically on one side of the tube alone, dangerous strains are likely to be set up by the opposite side unless the tube is periodically heated all round (as in the case of a large T-joint) by a large flame, and finally annealed and cooled with great care.

We may now proceed to discuss the characteristics of three further types of joints peculiar to general vacuum technology.

(6) *Joints* in situ.

The first type is the one required when assembling together the parts of an elaborate scientific apparatus; these parts being small enough to be handled and worked directly in the flame. Sometimes a number of these pieces are available ready-made, and the operation consists only in making this type of joint between the pieces, using tactics peculiar to this work. To begin with, every opening except the two ends (preferably of thick walls and equal bore) to be joined and a third to blow through must be closed by corks or pieces of rubber tube plugged at one end. The opening to blow through must be fitted with a sufficiently long rubber tube ending in a short bit of narrow-bore glass tube serving as a mouthpiece and preferably arranged to open downwards, and located beyond an intervening clamp or support, as shown in Fig. 15. In this way the weight of the tube or any accidental pull on it will neither cause a strain on the ends joined, nor a sharp bend choking the passage. Since it is not advisable to contaminate the inner walls

of the work by the condensation of moisture from the mouth it is better to interpose in the middle of this blowing tube a short length of glass tube containing a

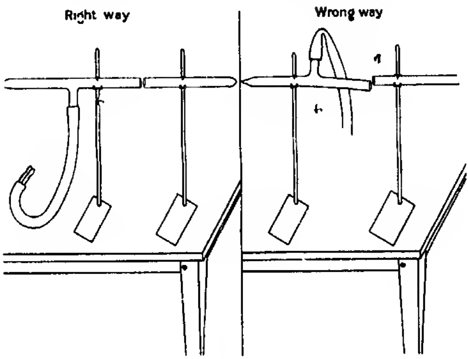


FIG. 15.

few lumps of fused calcium chloride or other drying agent. Such a drying tube shown in Fig. 16 is easily improvised, and preserved when out of use by connecting the two ends by the rubber tube used for blowing, the

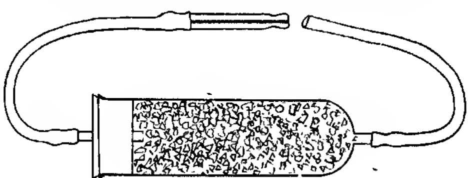


FIG. 16.

corked end of this design permitting of easy refilling with fresh drying agent when required. Since the blowpipe (and bellows) have now to go to the joint instead of the joint being taken to them, it is screwed out of its base for use as a hand blowpipe and fitted with extra lengths

of rubber tubing to permit of the free movement of the flame all round the joint. The two common accidents resulting from the movement of the connected tubes are either their slipping off through an accidental pull or the flame going out. These two contingencies must be carefully guarded against, the former by secure fastenings of the tubes, and the latter by the provision of an idle flame near by to relight the flame without delay.

The component parts are assembled on the table and clamped lightly so that the weight of the apparatus is properly supported without strain at any joint. While the weights of both the ends to be joined are fully taken by the supports on either side, at least one of the ends must have a freedom of motion along the axes of the tubes to the extent of about 1 cm., and this motion must be effected without bringing into operation any unbalanced forces. It is a wise plan to design the apparatus and its component parts so that this condition is easily fulfilled, irrespective of the ends to be joined being arranged horizontally or vertically. The ends to be joined having been properly aligned, the right end is clamped rigid and the left end kept half a centimetre away from the right. They are then softened uniformly all round by a wide flame waved about by the right hand, the mouthpiece being already in position for blowing. When the ends have been sufficiently softened, the free end is pushed (by the left hand) into sealing contact with the right end and the joint worked uniformly all round as a case of line joint, by the patch by patch method, a smaller flame being used.

The beginner will find that there are many things apt to go wrong in this operation. While he is heating the ends the portion of the tube facing the flame gets hotter and softer, and shrinks away, as in Fig. 17 (1), from the capillary action of the fluid glass. If one side

gets shrunk more than the other, the shape is distorted, and when they are put together sealing contact all round the joint cannot be secured. This is likely to happen especially when the ends have not been well softened all round, and hence would not permit of being pushed together close enough to seal up all openings. To guard against this, the tubes should be carefully and uniformly softened all round by waving the flame as much as possible, and at least a quarter of a centimetre of the glass on both ends well softened before the tubes are put together. If a hole develops, notwithstanding all these precautions, there are two possible ways of closing it. The first is to heat the whole of the joint with a large flame, push the ends together by the reserve freedom of half a centimetre of motion, and see whether the hole gets closed. If it does, the amount of local distortion this operation may cause at the joint may be set right by judicious heating and blowing. The other remedy is to have (always ready at hand) a piece of waste spindle drawn out of the same kind of tube, and then, having plugged up the hole by the sphere of glass formed on heating the end of this piece, to soften the joint and blow out the irregularity caused by this blob of glass. Whenever a hole like this is inadvertently caused, the main thing to be avoided is to soften the glass in its neighbourhood, since this tends only to make the hole larger and larger.

In such remedial operations, since the glass gets considerably distorted at times, it cannot be worked uniform again without an adequate knowledge of the characteristics of heated glass. If, as in Fig. 17 (2) adjacent regions of thick and thin glass are formed, a general softening of the whole, followed by a blowing out, would only tend to make the thin region thinner still, leaving the thicker region scarcely affected. On the other hand, if

the region is slowly softened down to shape (3) the thicker region has time to get softened and can then be blown out after a short delay to let the thinner region cool ; the effect is to blow out the thicker region alone, and thus tend towards uniformity (4). This is a consideration of prime importance regulating the type of heating and blowing to be adopted in general glass work, and we shall have to refer to it again when we come to blowing bulbs. Another point to be remembered in the use of the mouthpiece is to keep the lips open during the heating of a joint, as otherwise the expanding air

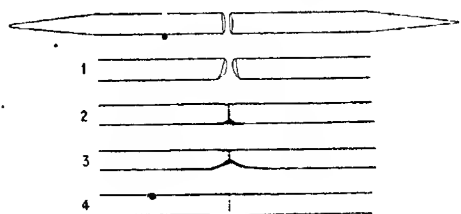


FIG. 17.

inside is likely to burst through the softened region at the joint. In awkward situations the pointed high pressure gas flame burning at the tip of a glass nozzle a millimetre in bore may be used instead of the blowpipe and bellows for effecting joints in tubes up to about 5 or 6 mm. in bore.

(7) *Cross Joints.*

This type of joint, rarely required and better avoided whenever possible, is illustrated in Fig. 18 (1), (4), and success in doing it is more a matter of satisfactory design than of difference in the working of the actual joint. Two tubes, A and B, having been joined on to the main

tube C*c* as two T-pieces, their ends have to be bent and joined together, a problem difficult to do according to the design (2), but easier by (3). The trouble with (2) arises because of the short leverage about BC, which gives no play to permit of the two softened ends being

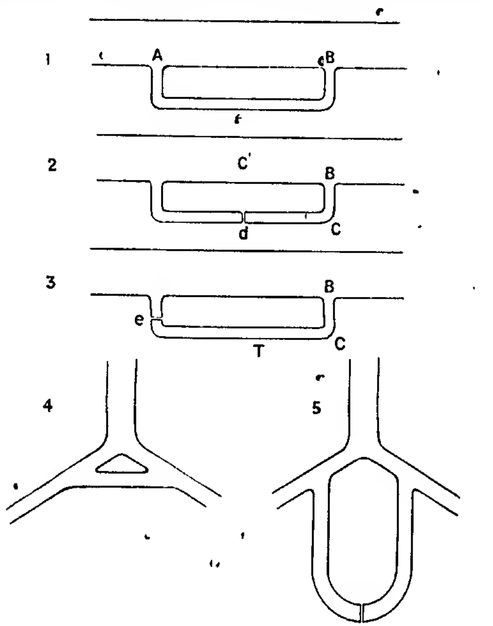


FIG. 18.

pushed together into sealing contact. With (3), on the other hand, the leverage about C*e* is larger, and the ends when pulled apart a millimetre or two can be softened and sprung together into sealing contact without undue strain on the joint at B. The joint is finished as usual, though at the end it must be subjected to a general

softening without any force on the arm T, and well annealed to relieve the joints of strains during the cooling and resultant contraction. Considerations based on this thermal contraction are also in favour of (3) and against (2), since the cooling of a joint at *d* is likely to strain the joints at A and B far more than one located at *e*. By such a procedure any cross-joint can be managed if the distance is sufficient to provide the requisite play. But where a short cross-joint (4) is required, trouble is experienced, and if permissible, a long tube may be bent back on itself as shown (5), thus providing a long leverage to effect the joint without strains. The aim in such cross-joints must be to secure always as large a leverage as possible, so as to minimise the resultant strains; thus ensuring not only an easier process, but also a greater factor of safety.

(8) *Joint on to Thin Glass or Different Kind of Glass.*

This is a special type of joint often required in general vacuum work, where a lead has to be taken out of a thin-walled vessel of the nature of a bulb to be exhausted and sealed. The usual process is entirely out of the question, since the reheating of a hole blown out on such a thin wall tends to enlarge it considerably. In such cases a blob of very hot glass is formed at the end of a tube or rod, and applied to the warmed surface at the spot where the joint is to be made as indicated in Fig. 19 (1). After a momentary interval to allow the extra heat of this blob to melt the thin wall in contact with it as well as cool round its edges, air is blown into the bulb, which operation tends to blow the blob of glass into a bulb on the side of the main bulb (2). If the glass is pulled out gradually during the blowing, this bulb is formed out into a conical thick-walled tube (3), which may be cut at the thicker place and a tube joined

on (4) without any difficulty, a comparatively fine flame being used if the cut is made near the bulb. The joint round A is perfectly uniform and thin, and hence likely to stand even if the glasses on either side of it differ slightly. Owing to this valuable property, two

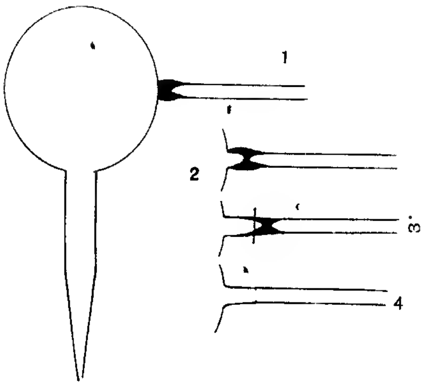


FIG. 19.

glasses differing considerably in their composition and coefficients of expansion may be sealed together by the interposition of a graded series of one or more joints of this type, blown thinner than usual out of glasses having intermediate expansion.

CHAPTER IV

BLOWING BULBS

In general, the blowing of bulbs may be classified under three principal heads.

(1) *At the End of a Tube.*

The first and simplest is the blowing of bulbs at the end of a tube. When the required bulb is small and with comparatively thin walls, the spindle on one end is melted off and the end rounded as for a test-tube. A length of tube at this end not exceeding twice the bore of the tube is softened down in a fairly large flame, a slow and uniform rotation being maintained to ensure equal heating and softening all round. When the tube has collapsed down to shape (2), it may be blown out gradually to the desired diameter (generally less than four times the bore of the tube if its walls are fairly thick), the glass being kept in steady rotation all the while. The successive stages of the operation are illustrated in Fig. 20. Any tendency to irregularity in the bulb (4) proves inequality of heating round it, and it must be carefully collapsed down again by means of a large brush flame and blown out again when the softened glass shows uniform colour indicative of uniform heating.

This operation is one of the simplest in glass-blowing, and even a beginner can manage to make a small bulb without much practice; he may then work on a larger bore tube to produce a larger size bulb. The point to

be specially careful about is not to get a waist of thin glass just above the softened blob of glass (6), and as a safeguard against this it is better to blow out a little during the heating and form shape (5) rather than (2) before proceeding to the final heating and blowing out to full size (3).

A good position to adopt in heating is to hold the tube almost vertically in a flame going up at about 45°, and to dip the tube gradually into the flame so that the extreme end is hottest and there is a minimum of heating at the neck. A convenient position for blowing when, as here, the mass of glass is small, is to have the tube pointing downwards and blow gradually with an increasing pressure as the glass cools.

We may discuss at this stage the shape the bulb takes according to the position in which it is held during the blowing. When the softened mass of glass is taken out of the flame for blowing, the air surrounding it, getting heated, rushes past upwards giving rise to a stream of cold air blowing upon it from below. If we hold the hot end down during the blowing, as in Fig. 20, this rush of cold air cools the bottom and hardens it while the sides and top regions are yet soft and continue to expand under the pressure of blowing. The effect is to produce a rather flattened bulb; thicker at the bottom. Though this thickness at the bottom is by no means a disadvantage when we have to join on a tube here, the tendency may be counteracted by giving an extra heating to the end regions of the softened blob before starting to blow the bulb. Thus quite a good spherical shape can be produced by this process. On the other hand, if the bulb is blown with the softened glass upwards the tendency will be to get a rather elongated bulb thin at the bottom and thicker at the neck. If the tube be held horizontally and carefully rotated while being blown to

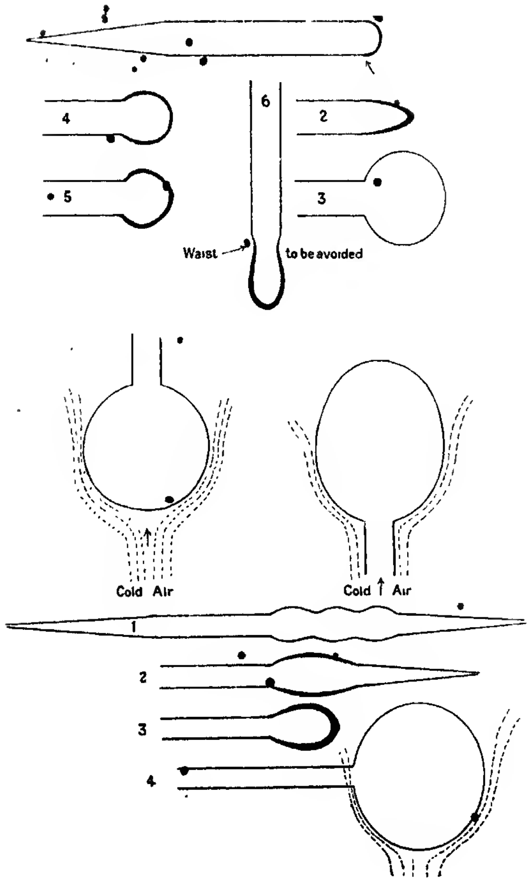


FIG. 20.

counteract the sagging tendency of the soft glass under its own weight, the cooling effect of the air current is equal all round and the result is a better approximation to a spherical shape. But evidently the use of this position demands greater skill, though any slight want of alignment hetween the hulb and the tube car be rectified by a judicious heating of the neck and centering by trial afterwards. But all these positions for blowing have their special advantages and uses as helps towards rectifying a wrong shape or thickness of glass, and by experience an operator may employ all these and other intermediate positions to remedy a faulty shape. For example, if at one hlowing a flat bulb with a rather thick bottom is obtained, to correct it, after collapsing the bulb, the blowing must be done with the tube pointing upwards, so that the flat bulh tending to get elongated blows out the extra thickness on top, and produces a spherical shape of uniform thickness.

When the bulb is to be rather large, the procedure demands some skill in collecting and handling the larger mass of glass required to give a reasonable thickness of wall when blown out. A much larger flame and even a bigger blowpipe may he necessitated to ensure uniform heating of the large mass. A device used with larger work is to have a heat deflector as well, so that a large zone of heat between it and the flame may be secured to soften the glass uniformly and quickly all round. This heat deflector is generally a slab of brick, fireclay, or ashestos fixed just beyond the flame.

There are two ways of securing the large mass of glass for hlowing. The first method is to collect it out of the tube itself gradually by blowing a few small bulbs adjacent to each other, as in Fig. 20 (1), and collecting them together little by little by the combined operations of blowing out a little and pressing together (2). For

tubes of average thick walls an approximate rule is to collect together a length of tube equal to the diameter of the bulb required, and during this stage the glass should not be blown out larger than is required to collect the glass. Finally, the upper spindle that served as a handle is removed, the conical glass left at this end blown round in continuation of the thick walls of the small bulb of glass, and after a strong final heating, the bulb is blown out gradually in successive puffs to the full size. During the collecting of the glass, it is likely to become distorted a little here and there, and the hot blob before blowing may have differences of temperature as well as thickness all round it, which may lead to distortion in the finished bulb. In such a case it must be collapsed back again slowly by means of a brush flame large enough to envelop the bulb, with occasional puffs to retain the spherical shape, and after a final heating blown out again with the necessary correction for the distortion observed.

At this stage, where we may have to correct for inequalities of thickness round the equatorial parts of the bulb, we may consider factors of importance other than the position of blowing, that influence the result. Since we endeavour to produce uniformity by thinning down the thicker regions rather than the reverse, a useful guide is to have always the thicker and hence hotter and brighter region facing upwards, and thus sheltered from the cold draft from below. Thus in the rotation of the work during the blowing, if a momentary stop is made as the brighter spots come up, it tends to make the bulb more uniform. For the same reason, the blowing must be gradual and not too sudden, so that the thinner regions are cooled earlier and stop expanding, while the thicker and hotter portions continue to expand, making the glass uniform in thickness and symmetrical in shape.

In the second method, a large mass of uniformly collected glass, in the form of a short tube of wide bore with thick walls, is used for the bulb, and the tendency to distort the glass during the collection as well as the time required for it are both considerably diminished. As in Fig. 21, a short length of the thick-walled tube is drawn (1), and a narrow region in its middle softened

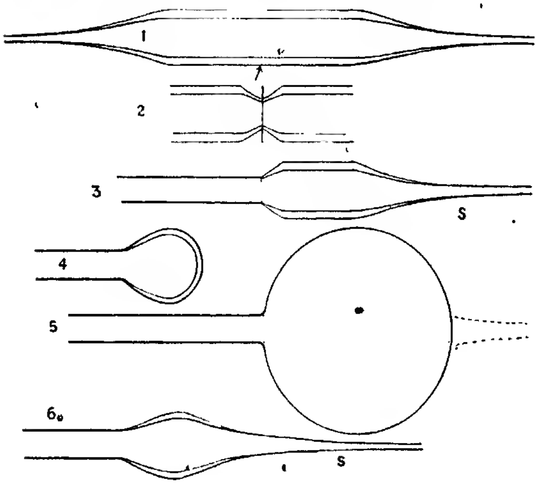


FIG. 21.

and pulled apart to give the thinner constricted waist (2). The two halves are severed by a cut at this waist, and the thick glass for two bulbs obtained at one operation, a procedure, adopted in the case of a pipette as well, that results in great economy of glass. One of these halves is joined on to the tube on which the bulb is required by a well-made pipette joint (Ref. p. 26) (3). The spindle S is drawn off and the end rounded and the

mass of glass slowly heated and formed into shape (4), and blown out as before. If the softening of the glass is carried right up to the pipette joint, and not beyond it, the bulb when blown will have the joint exactly at the neck, a position in which it is visible only on very close scrutiny.

(2) *Bulbs in the Middle of a Tube.*

The second type of work occurs when a bulb has to be blown in the middle of a tube. This is a specially troublesome job for the beginner, since the softening of the glass in the middle, combined with his lack of dexterity, makes continuous rotation and uniform heating impossible, without the softened glass in the middle becoming screwed in a short time. Experience in rotating by both hands at the same rate has to be gained by practice. It is easier to do it very slowly, so that the eye can follow the motion and check readily any tendency of one half of the tube to gain on the other. During the heating an inclination to pull the two halves apart should be strongly checked, and any tendency to push them together slightly encouraged. When the glass has become fairly soft, but not much collapsed, it is taken off the flame and blown, the hands keeping their distance apart and maintaining the rotation without distorting the glass in any way. Small-size bulbs can easily be blown like this by a single heating if a sufficient length of the tube is softened by the use of a large flame.

For the larger sizes we shall have to collect a mass of glass by either of the methods described in the last section. The adoption of the second method, employing a middle section of thick-walled tubing, is specially advisable for such work, since the production of a symmetrical shape is somewhat difficult, though essential in this work. After effecting the pipette joint on one

side, the spindle on the other side is melted off, and a hole blown out to make the joint on this side. Though a presentable piece of work to serve the purpose may be managed without much skill, to produce a good specimen with a large-sized bulb, symmetrical and coaxial with the tubes on either side, is a matter of great experience and dexterity. In fact, it forms a good test of skill in glass-blowing, and a good exercise to acquire the skill is to practise blowing shape 1 of Fig. 22 into a large thin-walled bulb (2), centred and symmetrical about the two spindles. A useful guide in this practice is to have the two spindles well centred and coaxial with the hot glass before starting to blow with the glass held nearly vertical in the left hand, which rotates the work vigorously without any restraint by the upper spindle held in the mouth with the right hand. By the residual heat of the thicker corners the two spindles are pulled out into straight alignment before the work cools down.

It may be of interest to mention at this stage the fact that, with a little experience, it is found easier to produce a symmetrical large bulb between a pair of supporting spindles rather than at the very end of a tube which is more suitable for use at the glass furnace. Hence large bulbs at the end of a tube are generally blown through the upper spindle used for the collecting together of the glass. After the thick piece has been attached to the tube forming the neck, as shown in Fig. 21 (3), the glass is collected into shape (6), and blown through S to form the bulb (5), the neck, held in the left hand, forming a substantial spindle to rotate the work in this operation. If it is too wide, then the stout spindle at its end is used for the purpose. The upper spindle S is then very carefully melted off, leaving only a very small pip at the bottom of the bulb indicative of its

existence during the blowing of the bulb. The pip itself, as well as the region of the bulb surrounding it, are softened a little for a final blowing of this region into uniformity with the rest of the bulb.

Such processes are in general suitable only for moderate size bulbs with comparatively very thin walls. The blowing of such articles as a big flask or the bulbs for an X-ray or positive-ray tube is in general beyond the

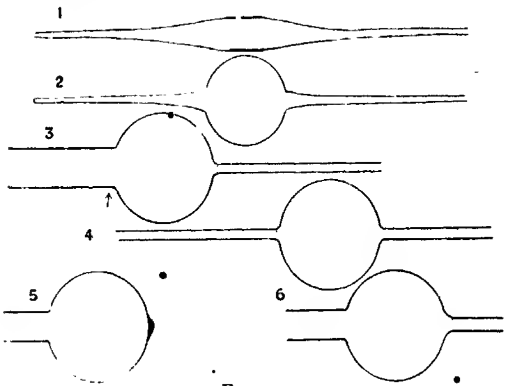


FIG. 22.

scope of table blowing, since it would be inconvenient and difficult to gather and work economically the large mass of glass required to give the walls of the large bulb a thickness of the order of about 1 mm., to enable further joints to be made on to them with comparative ease. Such bulbs are blown directly at the glass works, where the requisite mass of glass can be readily gathered directly from the pot and blown to any size without difficulty. It is advisable to make the tubes (for the purposes of joining on to the bulb at the table) preferably out of the same melting at the same time, so that trouble may not

be experienced in joining the tubes to the bulb at a later stage in the laboratory.

In concluding this section we may also mention a beginner's device. He can easily improvise a good-sized bulb in the middle of a small tube by first blowing a large stout-walled bulb at the end of a large tube, see Fig. 22 (3), and then joining on to its bottom a small-size tube. This operation is repeated on the other side if necessary after the larger tube has been melted away close to the bulb, and the glass in the neighbourhood formed into continuation with the rest of the bulb by a careful softening of this region round the tube, and blowing (4).

Joining on to the thin walls of a bulb is rather risky at times, and if the special procedure suggested for it earlier is not adopted, a useful method is to form a thicker region of glass locally by adding a blob of glass (5) where required, and spreading it out by blowing. Now, if a hole is blown out in the middle of this thickened patch, a joint can be worked here satisfactorily without introducing any serious deformation.

CHAPTER V

ENCLOSED WORK

A TYPICAL work of this nature is the making of a double-jacketed condenser. It serves very well to illustrate the special feature of this class of work, namely, the process of working the second internal seal. The inner piece A, whether tubular or spiral, is got ready first, and its open ends on either side slightly enlarged to form thin protruding lips. It is then slipped into the outer tube, one end of which has already been drawn down to a spindle, and then this end is also drawn out as shown in Fig. 23 (1), care being taken that the outer tube is rather too long than too short. After being softened down at ↗, it is pulled out a little to form the thick-walled enlargement C (2), the object of which we shall see later. The narrow waist beyond it is now softened down to a smaller bore than the enlargement at the end of A (1), which is then slid into contact and the junction fused down to establish all-round sealing contact. It is then blown out and the joint worked uniform as a simple case of internal joint (Ref. p. 31). The bulb C is now softened and blown out and drawn apart to form the connecting tube *d* (3). If there is not enough glass in C to form the tube *d* to the required dimensions, the short tube so formed may be cut off a centimetre beyond the joint as indicated, and a regular tube joined on, the internal joint being carefully kept hot during this operation by the use of a large flame, and the joint partly grazed as well at times.

Before the joint is allowed to cool, the side tube *s* has also to be joined on, and to prevent the cooling of the internal joint in this operation it is safer to do it quite close to this internal seal in the position shown rather than in the dotted position indicated. Further, unless the whole of the joint has been kept hot during the working by the frequent use of a large flame, it is inadvisable to try any annealing over a smoky flame. It is safer to let the work cool by itself, and rely on the annealing the joint has received during the working of the other joints. The joint on the other side is started in the same way, and when sealing contact has been established all round, the blowing has to be done through two openings on either side of the joint, since there is no through communication from one side to the other. The first puff is blown through S, the side less heated, and the rest through 4, the glass outside the joint being hotter and thus retaining the heat during this slight delay. The same effect can also be achieved by joining T and S by a rubber tubing and blowing through 4 alone, but is not recommended here for the reason that it will seriously interfere with the free rotation of the joint in the flame. The joining of a longer outer tube, as well as a side tube on the other side for the outflow, are also effected immediately as before and in close proximity to the internal seal. This joint should be kept hot all the while, and cooled off after a carefully prolonged annealing, to ease the strains resulting from the fixity of the other end. The wider tube D for corks may also be joined on if necessary before the spindles are all cut off, and the edges polished in the flame to give the finished specimen.

A spherical condenser is only a special case of this kind of work employing a sufficiently wide and short length of outer tube to enclose the inner bulb. By a judicious blowing of the outer tube beyond the joints into a regular

hemispherical shape, with no cylindrical connecting tube between them, the tube form of the outer envelope dis-

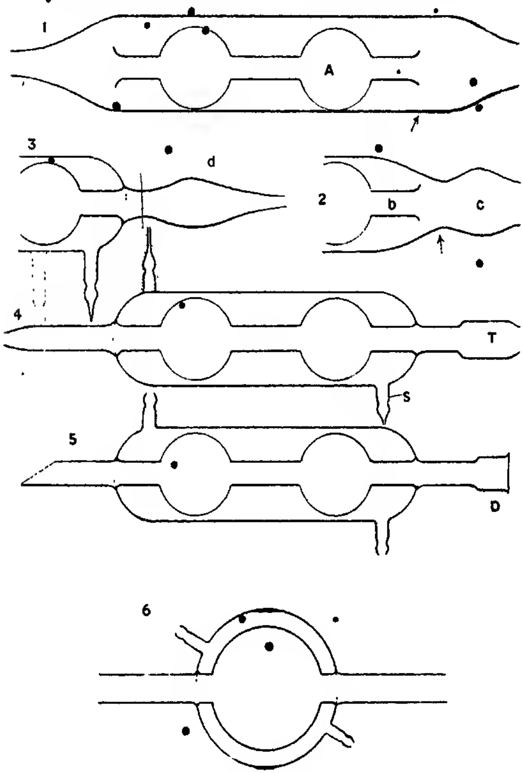


Fig. 23.

appears, giving place to a nearly spherical shape, as shown in Fig. 23.

An alternative method of doing jobs of this kind is

to divide the outer envelope in two by a sharp and square cut, taking care not to chip off any portion of the edges if the method of leading the crack round by a hot point is used. After the inner piece is introduced, the two halves are put back in their original position, and because of the perfect and almost air-tight fit all round the cut, the joint can be fused together again without leaving any marked trace. The internal seals on either side are made as usual, and in case there is no lead from this outer envelope, a temporary lead for blowing purposes must be formed near one of the internal joints, though it may be sealed off after effecting the second seal.

Bulb inside a Bulb and Vacuum Vessels.

It is often a case of wonder to those who do not know the process, how a large bulb (as in a Dewar flask) got inside another through the narrow neck. The process does not seem to have been described in any books on glass-blowing, 'though it is comparatively simple, and finds large application in general vacuum work. The usual procedure is to blow the outer bulb first (or get it blown from the glass works) at the end of a comparatively large bore tubing, and then join on to it the smaller piece T at the opposite end for blowing and other purposes, as in Fig. 24. At the end of another tube B that will readily slip through the neck of the wider tube with ample clearance, enough glass for the inner bulb is collected, and when softened down to a size that will easily slip through the wide neck of A, it is carefully introduced into the bulb through the neck and blown in this position (1), due care being taken that the hot glass does not come into contact with the outer bulb anywhere during the rotation of the work in blowing the inner bulb. Because of the outer envelope of glass

the inner glass remains soft much longer, and hence the blowing must be carefully regulated to prevent its being blown out into contact with the walls of the outer bulb. It is better to keep the outer bulb clamped for convenience in doing small-size work, while for the bigger-size bulbs an assistant's aid is also required to warm up the outer bulb while the glass for the inner is being softened, and then to bring it up and hold it in position for the blowing.

Dewar Flasks and Tubes.

Having described the process of blowing the inner bulb, we may at this stage discuss the further procedure by which the ends of the necks are joined together to form a vacuum flask. The neck of the outer tube having been already cut square by the bent-wire method (see p. 15), the neck of the inner tube has to be cut longer by nearly double the clearance between the two bulbs, so that there may be enough glass to push the line of joint on to the outside of the neck and thus away from the hot or cold fluid introduced into the finished vacuum flask. By a wooden bar pushed through the back tube the neck of the inner bulb is kept pushed out as in Fig. 24 (3), and the edge softened and enlarged to a size large enough to cover the neck of the outer bulb.[1] The two ends are now fused together into contact without holes, and the joint blown out uniform through the back tube T. During this blowing the tendency of the neck of the inner bulb to be pushed outwards as illustrated (Fig. 24 (5)) must be counteracted by pushing

[1] The risk of softening the neck of the outer flask in this operation, and causing it to stick to the inner, can be avoided by inserting a piece of asbestos cord round the neck of the inner flask, to keep it well separated from the outer flask. After effecting the enlargement, this separation piece can be taken out with the help of a bent wire before sealing the lips together.

in a wooden rod as shown by the right hand (4). Now the irregularities of the joint will get blown uniform with-

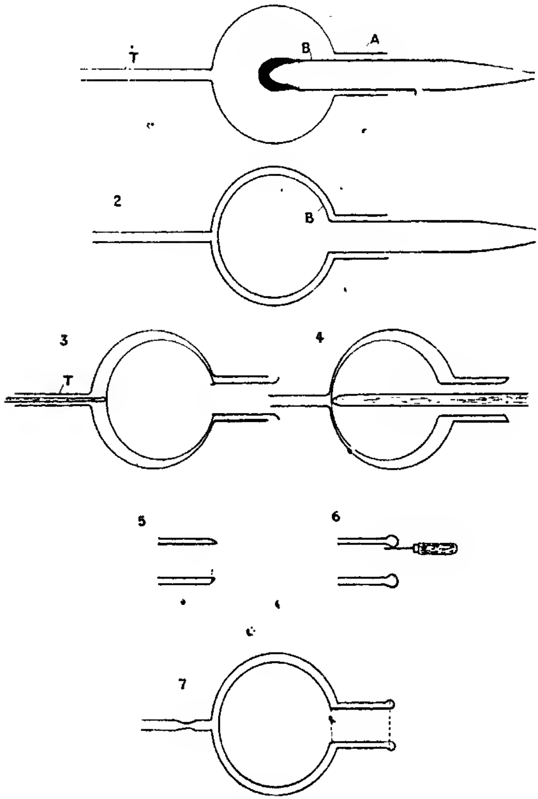


FIG. 24.

out the line of joint being pushed out beyond the small extent permissible and necessary to bring the inner bulb

concentric with the outer. Another tendency of the joint noted at this stage will be for it to get blown too round and bulging, and thus constrict the aperture at the neck as shown (6). This must be rectified by turning this softened enlargement pressed against the spinning tool as shown, without exerting any undue force to push back the bulging glass. Before annealing and cooling the joint, the inner bulb must be adjusted concentric with the outer. The finished bulb, with the joint located well outside the tip of the mouth, is illustrated in Fig. 24 (7).

For a cylindrical Dewar tube, two wide tubes, one sliding inside the other, with an all-round clearance of at least 2 mm., have to be drawn off with stout spindles at one end and the other end cut square at the right length by the bent-wire method. Corks provided with central tube have also to be got ready to close these open ends when required, as shown in Fig. 25 (1). The spindle of the outer tube can be drawn off, the end rounded to perfect hemispherical shape, and the end tube 2 joined on to a hole pierced at this end (2). The inner tube being held by its spindle, its square-cut end is enlarged to cover the bore of the outer, and then closed with its cork and tube; its spindle is then drawn off and the end blown hemispherical. The inner tube when cold can be slipped into the outer, the ends in contact fused all round, and the joint worked uniform and smooth as above. The heating should be only right on the end face, and tendencies of the inner tube to project out or bulge at the neck must be rectified as before by the use of the stick and the spinning tool, as indicated in Fig. 25 (4), and explained above.

The manufacture of Thermos flasks also belongs to this class of work, and is done on the same lines, excepting for a change in the procedure owing to the narrower

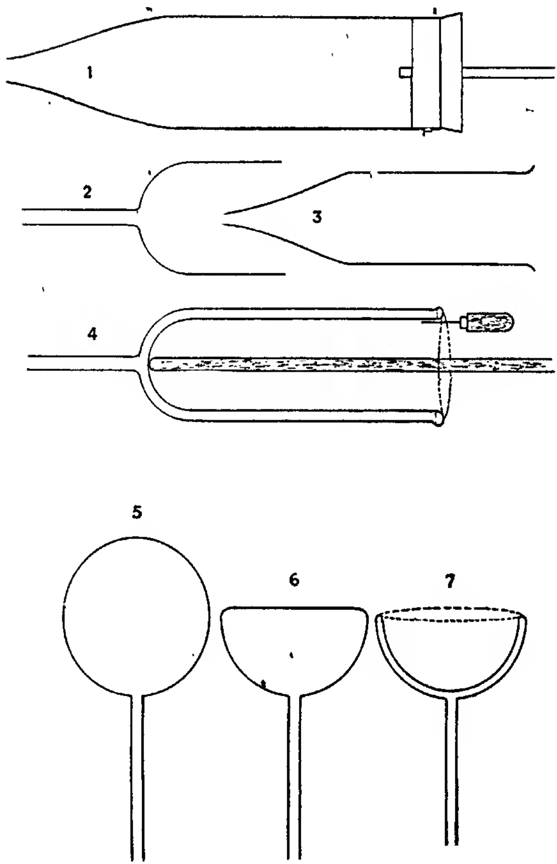


Fig. 25.

mouth-opening required. The necks of both tubes having been drawn out to the narrow bore and cut at the right length, the inner tube has its bottom rounded, and is slipped into the outer tube through the wider bore at the back as shown in Fig. 26 (1). The excess length of the outer tube is drawn off behind into a stout spindle, and the projecting lip of the inner tube enlarged and the joint at the neck effected and worked uniform as before. The glass at the head of the spindle is blown to a hemispherical shape and the glass of the spindle itself collected and drawn to form the tail tube for exhaustion and sealing purposes (2).

An interesting and simple work of this class is the vacuum bowl illustrated in Fig. 25 (7). For this a bulb is blown at the end of a tube, and the outer hemisphere of it slowly softened down in a large brush flame to shape (6) and then gently sucked in, when the shape (7) results without further ceremony.

In all these and like cases, where a comparatively heavy mass of glass has to be supported and handled in uniform rotation by one hand, the supporting tube T, or the spindle drawn for the purpose, must be substantial and extra strong to take up the load without danger of fracture at a critical moment. Mechanical aid in the form of a support to take the weight is resorted to sometimes, and in general it takes two shapes. In the first, we have two horizontally pivoted cylindrical wooden rollers on a suitable stand of adjustable height, and the bulb resting on these rollers can be rotated easily without any exertion, as shown in Fig. 26 (3). In the second type, we have a wooden bar with a notch at one end, the other end being held by the right hand with the neck of the bulb rested in the notch, when a region beyond the neck is being worked as shown. But evidently this latter process keeps both the hands occupied, in addition

to providing a very fatiguing and unsteady support, and hence the former method is to be preferred in every way.

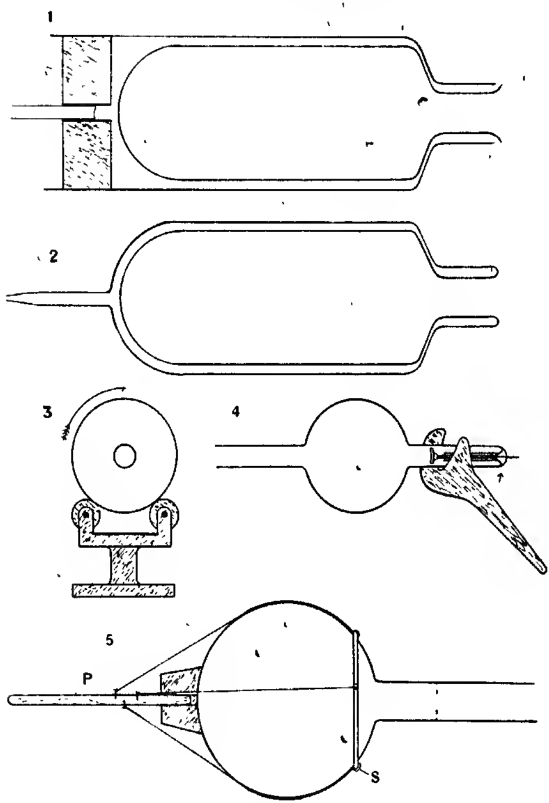


FIG. 26.

Occasions arise when a tube has to be joined on to the neck of a ready-made bulb, which is found too short for the purpose. It is difficult to keep a hold on the bulb

by the left hand fingers even in the smaller sizes, since the walls of the bulb become too hot to be handled with comfort. Fig. 26 (5) illustrates a contrivance I have often used to get over this difficulty. A ring of twisted copper wire S is formed and slipped over the neck of the flask and tied up with fine copper wire at three or more equidistant places, to small nails or screws on a wooden rod P serving as the handle. This rod has a large cork fitted tightly at its end, resting against the back of the bulb, and the surface of the cork may be hollowed a little to suit the curvature of the bulb, and thus ensure better frictional grip when the binding wires are twisted and tightened up. After the bulb has been adjusted into axial alignment with the rod P, the work may be rotated steadily for effecting the joint on the neck or anywhere beyond it.

Electrodes.

The fitting of electrodes occupies a prominent place in glass work and peculiarly so in vacuum work, where it is frequently required, and that sometimes on a massive scale. Electrodes form a constant source of trouble if not fitted properly, especially if the work begins to reveal its leaking or cracking propensities only at a later stage when it is difficult and often dangerous to reheat it again for repair.

In the simplest cases if a piece of fine platinum wire is put through a hole in the walls of the glass tube, and the glass well melted down on to the platinum and then blown out uniform, a satisfactory air-tight joint is produced, establishing electrical connection sufficient to serve the purpose. But any want of equality between the coefficients of expansion of the glass and the platinum leads to cracks or leaks sooner or later, especially if the wire employed is thick, and hence it is the general practice

to introduce an intermediate material between the two in the form of an enamel, of which there are a lot of varieties in various colours. Ordinary colourless soft lead glass or the variety of blue or white enamel glass serves the purpose admirably, and they are available in the form of small sticks about a tenth of an inch in diameter. The resulting procedure for a simple electrode at the end or side of a tube is illustrated in Fig. 27. The enamel glass is drawn into a fine rod less than a millimetre in diameter, and the platinum wire being held in the flame by a pair of pincers (very necessary in this work), an oval bead of the enamel glass is melted on to its middle and well fused in position. A small patch of glass on the tube is heated by a pointed flame and pulled out by sticking a waste spindle on to it. The tip of this conical projection is broken by a scratch from the knife or file and a hole smaller than the bead on the platinum wire is the result. The electrode is then introduced through this hole and held in position by the pincers, while the bead of enamel is fused on to the outer edges of this hole by a sharp flame. The whole of this electrode region is well fused together without softening an unduly large area, and care is taken that the platinum wire inside does not sag down and make a contact with the glass elsewhere. It is then blown out into an imperceptible hump on the tube, and the operation repeated to secure a symmetrical and graceful shape before annealing and cooling the work.

In general it is not safe to leave the platinum wire sticking out and make electrical connections straight on to it, since it breaks easily at the joint if the wire gets bent this way and that a few times. Hence the usual practice is to loop the wire outside and embed this end also in the enamel at the joint, thus providing greater mechanical strength for the platinum loop. But this

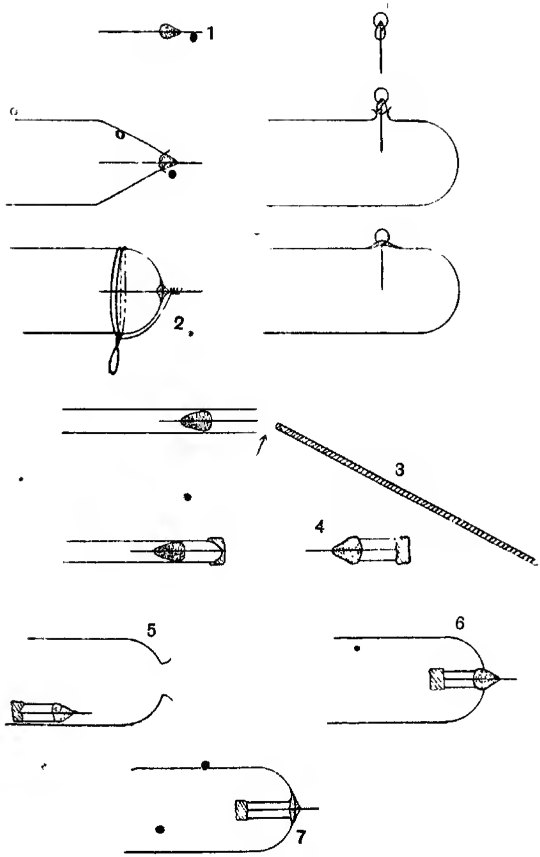


FIG. 27.

necessitates a greater length of platinum wire, which is rather costly, and hence to be very sparingly used. A common and simpler plan is to leave a short length of platinum wire projecting out straight, the electrical connection to it being made through a piece of fine copper wire twisted a few times round the glass tube, and then the end twisted round the platinum wire as shown (2). Thus all mechanical strains are taken off the platinum permanently, the connections being made always to the outer end of the copper wire twisted into a loop.

For general vacuum work these simple electrodes are not satisfactory enough, since the unprotected state of the platinum wire inside limits its current-carrying capacity. In discharge tubes, for want of sufficient surface, the wire will get too hot if the discharge starts directly from it, and hence it must be sheathed by a small tube of glass and thus used only as a conductor to the electrode proper, having a greater mass and surface. Further, the marked sputtering platinum exhibits makes it unsuitable for an electrode. In this respect, aluminium is far superior to platinum, and its lightness is also greatly in its favour wherever large electrodes to carry heavy currents are required. In such cases the electrode surface of aluminium is fitted on to the sheathed platinum in either of two ways.

With small discharge tubes, where the electrode need not be extra heavy or large, the simplest procedure is to melt a bead of aluminium on to the top of the projecting platinum wire itself as follows: A piece of aluminium wire about 30 cms. long and 2 mm. in diameter is kept ready for such purposes (the long length being simply for the sake of convenience in holding it comfortably when one end of it is heated). A small length of narrow bore-glass tubing (a waste spindle) of

about 2 mm. external diameter and 1 mm. bore, has a small length of platinum wire with a bead of enamel glass already formed on it, placed at its one end as shown in Fig. 27 (3), with a millimetre or two of the platinum wire projecting out. This is held by the left hand, and the aluminium wire by the right, and the end of the aluminium wire is then melted in a rather pointed flame, and coated on to the projecting platinum and glass. An irregular bead of aluminium in metallic contact with the platinum is thus formed at one end of the sheath of glass. It is now broken off from the rest of the tube just opposite the bead of enamel, and by the addition of a further lot of enamel all round the bead, the tube is sealed to the enamel at this end as shown (4). The bead of enamel should be now larger in diameter than the glass tube forming the sheath, and of the conical shape indicated in the figure.

When a heavier electrode is desired, the usual practice is to employ a short length of stout aluminium rod or wire for the purpose, and in this case the platinum wire may be fused to one end of the aluminium wire filed conical, as shown in Fig. 28 (1) and (2). Another method of effecting the joint between the two is to drill a small hole at the end of the aluminium rod, and after introducing one end of the platinum wire into it, to roll the aluminium down tight into gripping contact on the wire. The bead of enamel may now be formed round the platinum and a close-fitting protecting tube of sufficient length slipped over the rod of aluminium. The bead of enamel is now fused into contact with the end of this tube to give the finished electrode element, as shown in Fig. 28 (1), (2), (3).

The procedure of fusing this electrode in position has to be somewhat different, in so far as the electrodes have to be introduced into the tube before the end is narrowed

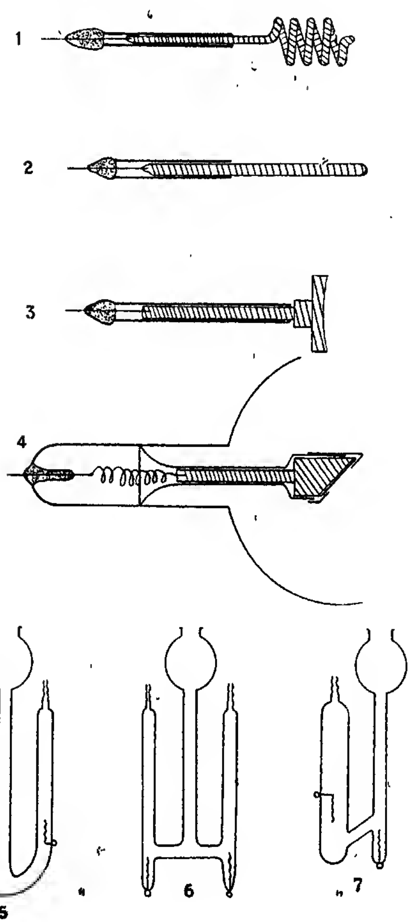


FIG. 28.

down to effect the seal. The best way is to pierce at the end of the tube where the electrode is desired, a hole larger than the largest diameter of the electrode. It is then slipped in in the right direction, and the end of the tube rotated horizontally and heated; as shown, the hole is thus contracted down until it is just too small to let the end bead of enamel slip out (Fig. 27 (6)). The electrode is now jerked into position and kept horizontal by holding the projecting end of the platinum wire by a pair of pincers; in this position a sharp flame directed to the joint fuses it on to the outer tube. The joint is worked uniform as usual with alternate softening and blowing, care being taken in the heating to see that the electrode does not get bent too much out of the axial position. When the joint has been worked uniform and symmetrical, the whole of the conical end of the tube is softened and blown out to a hemispherical shape as shown in Fig. 27 (7), and annealed. If the initial bead of enamel has been made conical and elongated, the inner glass sheath would not have any contact with the outer walls except through the short intermediate column of enamel, and at the very root of the projecting platinum wire there will be a tiny conical lump of enamel projecting out of the hemispherical end, as shown in Fig. 27 (7). This latter is an advantage rather than a disadvantage, since it provides additional mechanical support to the projecting platinum.

When still heavier electrodes are required, as with some types of X-ray bulbs and rectifying valves, the large mass of metal forming the electrode has to he given extra mechanical support. The tube forming the tight-fitting sheath round the stem of the electrode has its outer end enlarged and joined on to the walls of the outer tube by a well-worked internal seal, as shown in Fig. 28 (4). The metallic electrode is also suitably clamped

to the glass sheath, and the connection to the short length of platinum, sealed in as usual, is through a spiral of thin copper wire.

Another class of electrode work occurs in improvising an electrolysis apparatus, of which the Hoffman's apparatus of Fig. 28 (5) forms a well-known example. Here two electrodes of platinum with leading-in wires have to be sealed to the side or end of two tubes. The fitting of the electrodes offers no difficulty, and for more than one reason it is better to have them at the end as shown in (6) rather than at the side. They are often found fitted on the side and projecting vertically up as shown (5), though there is great risk in this method—not so much in the making, but in actual use. By the generation of gas for some time, when the level of water sinks below one of the electrodes the current becomes interrupted and sparks take place between the wire and the liquid; this often occurs right at the joint, with the unpleasant result of a crack at the joint. If the electrode is bent down instead of being turned up, the interruption of current and spark takes place at the metal tip far away from the glass or joint without any serious consequences. The form of electrolysis apparatus shown in Fig. 28 (7) is specially suitable for vacuum work, where often only one of the gaseous products is required to be fed steadily into an apparatus. By the use of this modified form for the electrode the battery may be permanently connected to the apparatus, and the current is switched on or off automatically as the level rises or falls by the escape or generation of gas in excess of the outflow.

CHAPTER VI

SPINNING GLASS

THE spinning of glass consists in shaping the ends and other portions of glass tubes into certain conical and cylindrical shapes by turning the softened glass in contact with an angular blade of metal. This is an operation largely used by experts in table glass-blowing work, though rarely described in any book on laboratory glass-blowing. The significant omission is probably due to the fact that the spinning of glass is more a professional than an amateur's type of work. But it is erroneous to think that it requires very great skill, and with a little practice a lot of work done by the amateur can be finished much more satisfactorily than at present. Further, the absence of any adequate description of the process leaves the laboratory student entirely at a loss to know how certain types of work, such as stop-cocks and conical ground joints, were ever made by a process of glass-blowing at the table. For this reason I propose to treat the subject in detail.

The few simple tools Nos. 3, 4, 5, and 6 of Fig. 3 are essential for this work, and all of them may easily be improvised in the laboratory, the blades of the right size and shape being cut out of $\frac{1}{16}$-inch brass or copper sheet and fitted on to cylindrical wooden handles. When the blade is brought into contact with the softened glass it gets too hot and is liable to stick to the glass, unless it is periodically rubbed over a lump of beeswax or paraffin

wax, that acts also as a lubricant. Further, since the glass has to be rotated backwards and forwards, while pressed lightly against the blade or tool, a truly centred strong axial spindle is an absolute necessity to produce circular symmetry in the worked end.

We can best illustrate the general procedure by describing how a trumpet enlargement is to be effected at the end of a glass tube. The piece of tube with the stout axial spindle is held in the left hand as usual, and its outer end softened in the flame uniformly all round, and most of all at the extreme tip. Tool No. 4 of Fig. 3, after a preliminary warming and rubbing over the wax, is applied horizontally into the end of the tube by the right hand, and with a gentle pressure against the side as the glass is rotated, the tool is gradually swung round towards the left hand so that the enlargement is first formed and then gradually bent back like the mouth of a trumpet, as shown in Fig. 29 (1) and (2). In fact, this is the way in which all enlargements at the end of a tube, big or small, are produced, since the application of a conical charcoal tends to compress, thicken, and distort the glass.

Three points have to be carefully attended to if success in the operation is required. The first is to have a gradation in the heating from the outer end inwards. The extreme end should be softened enough to look quite orange-yellow, gradually merging into the faintest red of the unsoftened portion of the tube. The second point is not to exert undue pressure in forcing the glass into shape. The glass must be soft enough to be gently pushed into shape on the merest contact with the tool. Thirdly, a vigorous to-and-fro rotation of the work against the tool must be maintained throughout the spinning operation until the glass sets hard. It should also be carefully annealed before being allowed to cool.

A better example of this type of work is given by a

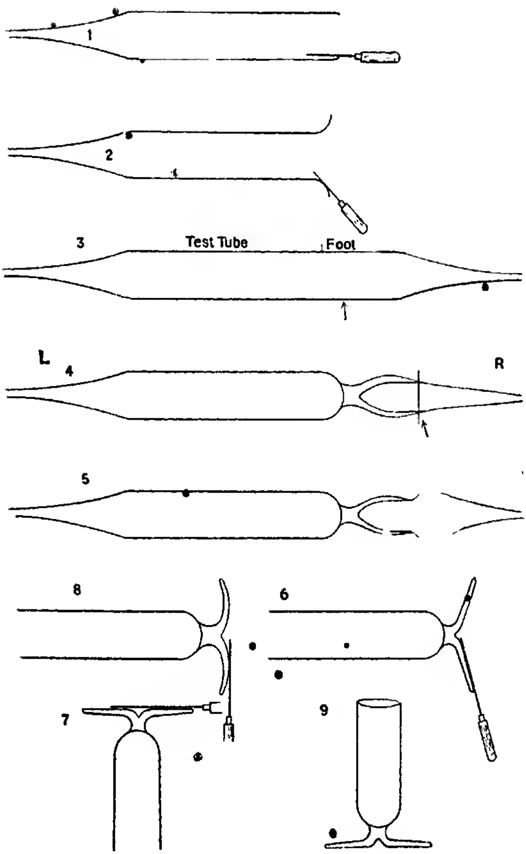


FIG. 29

test-tube on foot. A tube of the form (3), Fig. 29, with spindles on either side, is drawn out, having an extra length equal to about twice the diameter of the tube with which to form the foot. The ends of the spindle are open on both sides, and if the tube beyond the portion required for the foot is softened down, it may be contracted and collapsed into contact as shown (4), forming a cylindrical short neck between the test-tube portion on the left and the foot on the right. By repeated heating at this junction and blowing in first at the left and then at the right end, the bottom of the tube is rounded and the glass for the foot collected together as for a bulb, care being taken to see that the cylindrical neck of solid glass is axial to the tube throughout the operation. The right spindle may now be cut off as indicated (4), or, still better, be blown off from it in a novel way as follows (5): The neck of the spindle is thoroughly softened and quickly blown out through R into a thin bulb or film which may easily be brushed aside to give the opening at this end. The edges of this opening are then softened and enlarged to make the glass for the foot form a cone. Then, after a strong heating and softening of the whole of this glass, it is enlarged out by spinning against the tool whose point conveniently rests in the central hollow of this cone which has not been softened. The result is the shape indicated (6), and before the glass loses its heat it is held upright and stroked horizontally with a flat-bladed tool to make the foot quite flat and horizontal but for a dimple in its centre (7). If during the spinning operation the tool is swung round quite normal to the horizontal axes of the tube the edges are likely to curl up as indicated (8), and hence the above procedure of flattening out immediately after the spinning is to be preferred. The other end may now be cut square and polished to give the test-tube on foot.

The making of a measuring-jar or glass on foot is also similar, except in the order of procedure. The mouth of the measuring-jar with lip has first to be formed at the end of a tube which has its other end drawn into a spindle. The mouth is then fitted with cork and tube as shown in (1), Fig. 30, and this tube forms the spindle for shaping the foot at the other end. The foot itself has to be attached separately, since the bottom of the measuring-jar is required flat. For this a short length equal to the diameter of the tube is drawn with a spindle at one end, the other end being rounded and then blown off to give the piece A (2). The spindle at the end of the piece B is drawn off and the excess glass carefully removed as for making a flat end for the tube. This end is then softened and blown flat against a flat-bladed tool, Fig. 3 (1). Immediately after, the piece A is joined on to the back of the piece B as shown (3), the joint being fused very well together and blown first into B and then into A. The right spindle may now be blown off as before, and the projecting short tube softened and spun out to form the foot as shown (4).

Another common laboratory apparatus made by the process of spinning is the common thistle funnel. The usual method given is to blow a bulb at the end of a tube and then soften and blow out the outer hemisphere of it. This leaves the rim quite rugged even after the best of trimming and polishing, and the finished article of commerce with its thick uniform rim is a source of mystery to the student who has tried making it. The real procedure is as follows: A length of wide-bore tubing is joined on to the tube forming the stem (5), and about three-quarters of the length of the wide thick-walled tube blown into a stout-walled bulb of diameter equal to that of the funnel desired (6). The right spindle beyond the short thick neck is blown off, and the cylindrical neck as

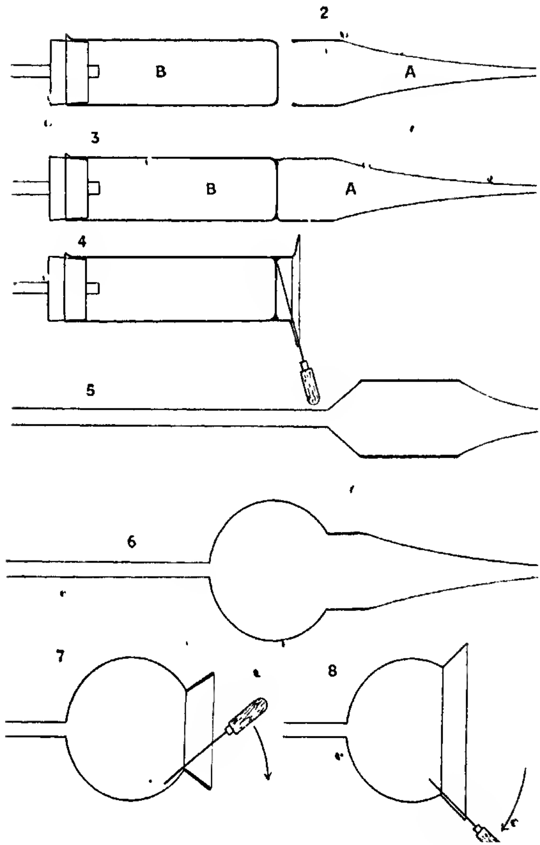


FIG. 30.

well as the adjacent region of the bulb softened, and first formed conical (7) and then expanded out as indicated (8) by spinning. The tool is introduced first as shown (7) to expand the portion of the bulb to give a wider neck, and then gradually swung round into position to spread it out as shown (8).

After this preliminary consideration of the process of spinning, we may now describe the two principal operations in vacuum technology that require the aid of the spinning tool.

The first and simplest one is the making of ground joints between tubes, since a large number of these are used in modern work. The ends of the tubes have to be shaped into cones of approximately equal angles and then ground together with an abrasive into a tight-fitting contact over the whole conical surface. The first piece to be made is generally the outer or (female) cone, the procedure for which is as follows: The standard piece having been drawn out (1), Fig. 31, the spindles are recentred with extra care, and at a distance from the right end equal to the diameter, the tube is softened round by a sharp flame and pressed together to give a ring enlargement (2). The right spindle is now melted off and the hole blown out at this end enlarged. The whole of this end is then softened right up to the ring enlargement and spun out (3) slowly into a cone, the angle of the cone being anything between 2° to 5° and not more. The operation must be repeated with lesser heating to ensure the conical shape with a true axial circular section. The spinning tool used must have perfectly straight edges, otherwise concavity or convexity in the conical surface may easily be produced, and extra grinding will be necessitated to eliminate them.

The other (male) half of the conical ground joint is started on in the same manner at the end of another

standard piece of the same size, with a ring enlargement formed near the right end. The glass between the spindle and the ring enlargement is softened, collected together, and blown into a small thick-walled bulb, which, when drawn out a little, forms the conical shape shown (5), Fig. 31. Any tendency to form a waist in this conical region must be counteracted by a puff blown in during the drawing out of the bulb into a cone, and any residual convexity of such blowing is either drawn down or spun down by rotating the softened surface against the flat blade of the spinning tool. It goes without saying that the angle of this cone should be as near as possible equal to that of the cone already spun out, so that they may fit each other with a minimum of grinding.

To those who find difficulty in the initial stages in making a correct judgment of this approximate equality at sight, the simple device of two angular templates cut out of a scale marked on asbestos board, or thin sheet metal, as shown at (6), may be of great assistance, the angle of the cones being equal to that of the template. When the outer cone has been spun to fit the template applied in it as shown, the divisions between which the cone fits are noted down. The blowing and drawing down of the male cone is now repeated until it also makes an approximate fit between the corresponding divisions of the V template. During the working it is dangerous to test the fit of the glass cones themselves, since they invariably stick and crack at the first contact. Another important point to be remembered in blowing and drawing the male cone is to have its largest and smallest external diameters CD and XY smaller than the corresponding internal dimensions of the female cone, so that the inner cone can advance freely into the outer to take up the wear of the grinding. Otherwise shoulders will be cut at the ends where the glasses bear against each other,

as shown in (8), and any further grinding tends only to widen and distort the gap between the two. In such cases, if the end responsible for this action is ground down a millimetre or two against a flat sheet of iron with carborundum powder, the grinding together of the cones may be proceeded with, and a satisfactory joint obtained. It is best to adopt the first process, where this trouble is entirely eliminated.[1] The excess length of the inner cone is cut off after the grinding by the hot joint, and the outer sharp edge of the cut rounded by rubbing over a piece of emery or carborundum paper.

An alternative method of forming these cones is by spinning them in a lathe, though it is generally practised only in the case of large cones with thick walls, where greater accuracy of initial finish is essential. The tube is then chucked in a lathe, and held firmly and well centred by a sheet of rubber wrapped round it. A quarter-inch brass or copper rod has a cone of the required angle turned for some length at one end, and forms the spinning tool when held horizontally in the slide rest, with its axes parallel to its travel along the lathe bed. The end of the tube is heated by a blowpipe flame in the left hand, as the tube is rotated, and when it is beginning to soften the tool is gradually advanced inwards by the right hand operating the slide rest. The end thus becomes expanded readily into an exceedingly uniform cone of angle equal to that of the tool. The lathe should be run slow to reduce the centrifugal action on the softened glass, and the rate of advance of the tool inwards adjusted to the degree of softening of the glass. After it has been carefully annealed to release the strains due to any unconscious forcing of the

[1] To keep the male cone axial during the initial grinding, it is useful to have a cork of suitable size fitted on to the spindle. The spindle is cut off after the grinding.

imperfectly softened glass, it may be cooled off and removed.

The male cone also should be spun in immediately after without the tool being unclamped in any way, so that the two cones may be of exactly the same angle to fit each other with the minimum of grinding. The corresponding tube having been chucked and centred on the lathe, the end is softened as before, and the tool advanced on to the work, with this difference, that it is now made to bear on the external, and not on the internal, surface of the tube, as shown in (10), Fig. 31. To secure this, the tool will have to be shifted back horizontally by a few millimetres before starting on the work of the inner cone. An exact counterpart to fit the cone already made is easily secured if the tool is advanced on to the work to the same extent so that the length of the conical surface is nearly the same.

The grinding together of the cones is most quickly accomplished in a lathe, though the smaller sizes can quite easily be finished by hand work. The best abrasive to use is fine carborundum, since it cuts much faster than emery. In the use of the former abrasive, it must be borne in mind that the best grinding takes place when the cones are held against each other without undue pressure. In the process of grinding the two halves must be lifted apart frequently and put together in a different orientation. When a good fit has been obtained without the slightest wobble, indicating that the two conical surfaces are in contact throughout, the grinding may be finished with a finer abrasive to give a smoothing finish to the surfaces. Any slight misfit between the two cones resulting from the slightest differences in their angles may be rectified quicker in the initial stages if the abrasive is judiciously applied only to that end that is coming into premature contact. If hand grinding

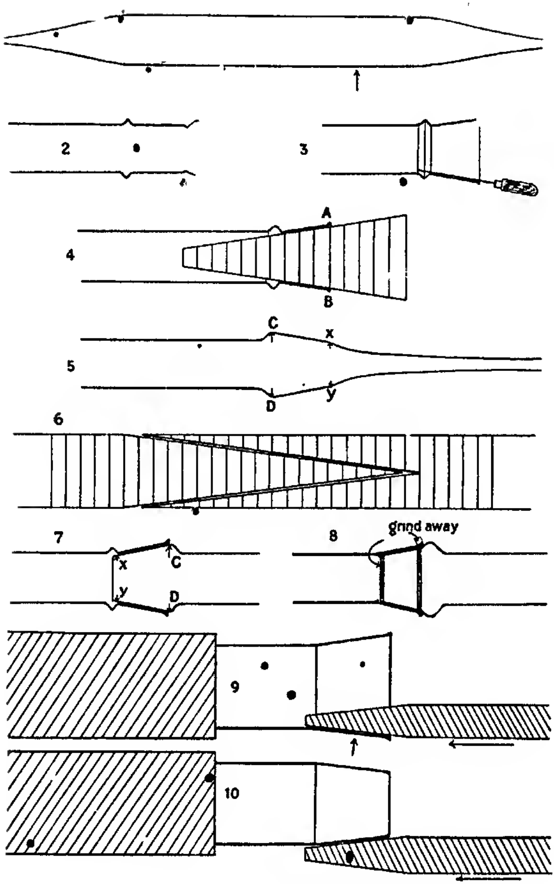


FIG. 31.

is resorted to, a further modifying influence can be exerted by holding the work vertical in such a way that the larger particles of the abrasive fall down under gravity towards that end that is giving the tight fit too early. During the grinding the abrasive should also be periodically moistened with a drop of water, just enough to prevent the cones working dry. After the grinding is finished, the tubes should be thoroughly cleaned and every particle of even the finest abrasive removed by scrubbing and then washed clean before drying. This last precaution is particularly essential if the joint is to be greased and used for vacuum work. A great many of the leakages observed with such ground joints are due to gritty particles remaining lodged between them, and often they are only the remnants of the abrasive that have not been washed away in the cleaning.

The second and more complicated work pertaining to vacuum technology is the making of glass stop-cocks. If any good commercial stop-cock is closely examined, traces of faint circular marks can be readily seen round the barrel and the thickened ends, indicating that they were made by spinning and not by a process of cutting out the length from the conically drawn end of a thick-walled tube. The actual process is to form the centre barrel or socket portion by spinning (for which operation ingenious ways of handling are necessary), and then to join on the side tubes to holes formed on the side of the socket. The side tubes with conically shaped thick-walled ends have first to be made, since they must be ready at hand to be joined on as soon as the socket has been spun out.

To make them, a foot-length of thick-walled quill-tubing is softened in the middle, and the glass pressed together and thickened so as to be of about the same external diameter, though the bore inside is reduced to

about a third of what it was, as shown in Fig. 32 (1). Before it has cooled down, a sharp scratch in the middle of this thickened region, followed by a brisk knock, severs the two halves, giving a square cut at this thickened region. Since this thickened end has to be heated later on, it should not be allowed to cool in the interval, and is therefore rested on a tripod stand with a spirit lamp flame a few centimetres below it. Such a practice is always used whenever thickened or worked regions have first to be got ready for use later on in the course of the work. One after another the thickened ends are softened at the extremity and shaped into a cone by spinning as shown (2), and then put back over the spirit flame.

To make the socket for the stop-cock, special tubes with thick walls (2 to 3 mm.) are used to save time in collecting the glass, and out of this our standard piece, with extra stout, well-centred spindles, is drawn out, as shown in Fig. 32 (3), the tubular portion in the middle being about 3 to 4 cm., according to the length of the socket required. The heating and softening of such thick-walled tubes should be done very gradually, and the whole of this thick-walled region is first blown out a little and drawn apart to form a conical shape. The right spindle on the wider side is then melted off, the excess glass removed, and the end blown away. This extreme end having been softened sharply and turned back a little by an act of compression against the spinning tool, the thickened end is formed into the triangular section shape by repeated spinning against the edge and flat of the tool. The whole of the conical barrel portion is now lightly softened and spun against a long tapering tool to finish a true conical surface inside. By an alternate application of a flat tool horizontally against the external surface, the latter also is worked quite conical without any convexity or concavity (6).

To form the other end of the socket the work has to be supported in a novel way on a bent temporary spindle which enables that end to be spun out into regular shape with equal ease. For this purpose, a spot on the side of the conical barrel where the side tube is to be joined on later, as well as the end of a foot-length of small size quill tubing, are intensely heated and stuck together to make a temporary joint. This tube is then bent round as shown (7), and adjusted to be in true axial alignment with the spindle on the other side. Now and hereafter, irrespective of the region actually softened for work, the whole of the socket must be kept hot by a periodical application of a broad brush flame, care being taken not to soften the joint of the bent temporary spindle in this operation. The work being rotated by the provisional spindle, the spindle on the right side may be fused and drawn off, and the conical thin projecting glass D left at this end is removed by a sharp scratch at its base followed by a gentle sideways knock. The small hole thus formed here is enlarged by spinning in the flame, first with a pointed pin tool, and subsequently with one of the tapering blade tools. The end ring is formed as before by compressing the softened glass and spinning it into shape. Any deformity in the conical shape of the socket at this end is also rectified by softening this end region and spinning it without enlarging it in any way. In fact, if the edge of the tool is applied flush with the conical portion already formed at the other end, the risk of such a deformation does not arise at all, and the end region easily makes a regular continuation of the cone already formed.

The socket being thus shaped, it remains only to join on the two side tubes. For this another temporary spindle, in the shape of a straight quill tube, is joined on to the diametrically opposite spot on the socket, and since

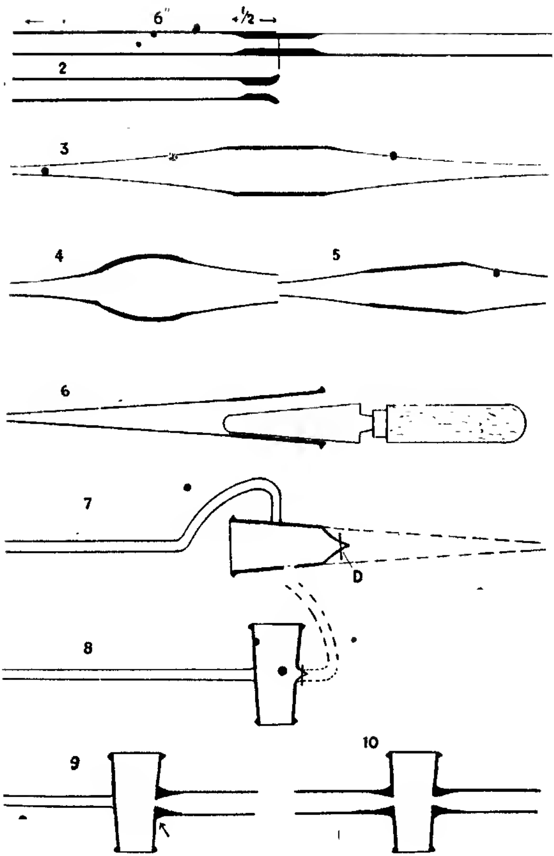


FIG. 32.

there is no further necessity for rotation about the axes of the socket, the bent temporary spindle may now be fused off as shown (8). The glass at the spot is carefully softened by a sharp flame and drawn out into a cone, which is then cut off as before at D, to give the small hole. This is enlarged with the pin tool, giving a hole with protruding outer lips. One of the tubes over the spirit flame is taken out at this stage and joined on to this hole, after the edges of the hole as well as the conical thickened end of the tube have been intensely heated. The intense heat softens the glass to such an extent as to make it flow, and the joint becomes completed without any further work. A little more finishing may be attempted with advantage by the application of a fine pointed flame all round the joint as shown (9), so as to make the glass at the surface fuse into continuity all round and flow from the thickened end of the tube on to the barrel. After this joint has cooled enough to be rigid, it is reversed, end for end, and the other temporary spindle melted off, the hole formed, and the second tube over the spirit flame joined on as before (10). The whole work must be thoroughly warmed up in a large flame and annealed very carefully before being allowed to cool, a separate annealing chamber being used in case a large number of stop-cocks are being made.

When the side tubes joined on are small-bore capillary tubes, it is often advisable to have at hand the assistance of a suitably mounted pin with which to open out the hole at the joint, as this is likely to contract or close altogether during the operation of joining the tube on to the socket. A long thin steel wire (knitting needle) may be mounted vertically on a block of wood, and if the hole has been choked up, the joint, after being strongly heated and softened, may be plunged straight on over the wire as shown, Fig. 33 (1), and momentarily pressed down

to re-form the hole. If only a widening of the hole is required, the short bent conical end of a steel wire on a handle may be applied momentarily, as shown in Fig. 33 (2), from the inside through the wide end of the socket, the joint having been thoroughly softened before and after to relieve all strains introduced in this process.

The inner piece or plug of the stop-cock may be solid or hollow, and the process of making them differs accordingly.

The solid plug is the easier to make, especially on a commercial scale, when it may simply be squeezed to the

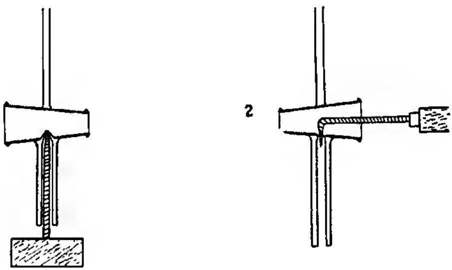


FIG. 33.

approximate size and shape in a mould by the glass-maker himself. It is also easily made in the laboratory out of glass rod worked into the approximate size in the flame, though the impossibility of enlarging a constricted portion by blowing necessitates a certain degree of skill and judgment in getting the piece into shape by a process of pressing together and pulling apart of the softened glass.

For the cross-bar or handle a small-size glass rod is drawn off with spindles as in Fig. 34 (1). It is then softened and constricted in the middle by pulling apart (2), and by a judicious series of softenings and drawings apart

shaped into (3), and then bent to the shape of the left half of (6), the horizontal spindle P being centred about the centre C of the cross-arm. For the barrel or plug portion enough glass out of a thicker glass rod is first

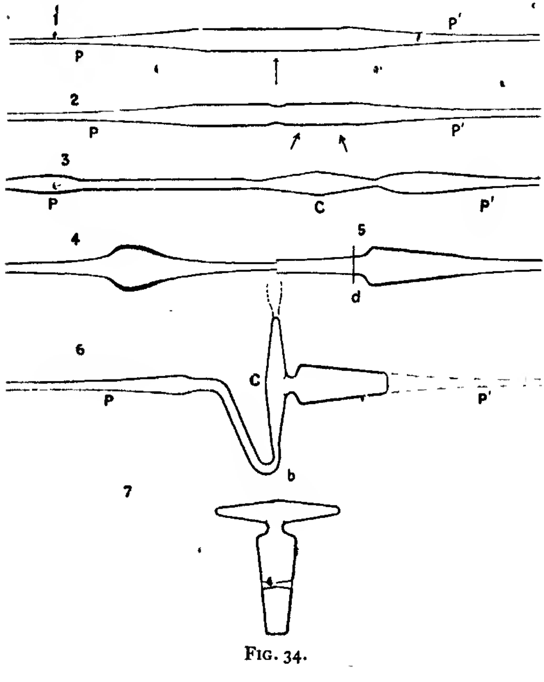


FIG. 34.

collected into shape (4) and then carefully drawn out to shape (5), a template being used as suggested before to get it of the approximate size and angle to fit the socket. The left spindle of this piece having been fused off beyond a short neck, the cross-arm and the barrel are fused together as shown at (6), the glass being heated and

softened almost white before being put together to effect the joint. Since the joint permits of easy rotation about the spindles P and P′, the joint is thoroughly fused into contact all round in a pointed flame. The spindle P′ on the right may now be melted off at the right length, and the end of the plug fused and compressed flat. The whole of the plug must be heated to redness and annealed to release all strains. When it has cooled, the bent supporting spindle P may be fused off at *b*, giving the finished blank for the solid stopper.

The stopper can now be ground in the socket with carborundum powder as before, until a good fit without any wobble is obtained. The position for the hole is now marked on opposite sides and the hole itself drilled half-way through from each side until they meet in the centre (7). The drilling is most conveniently done in a vertical drill, where the very gentle pressure with which the drill should bear on the glass is fully under control by the hand. The drill itself is a conical square piece of hardened steel with its ruggedly broken end as well as the sharp ground-down edges acting as the cutting points. The ground-down end of a small triangular file has the requisite hardness, and out of this the drill may easily be improvised. A freshly prepared solution of camphor in turpentine acts as a good lubricant, giving the drill a grip on the glass.

The hollow stopper is made largely (in the larger sizes) to lighten the stop-cock, and it is blown at the table with comparative ease, though it is difficult for the student of glass-blowing to guess the process by which the inner communication tube is sealed in. The initial procedure is exactly identical with that already indicated in Fig. 34, with this difference, that instead of glass rods, glass tubes are used, and they are worked to the same shapes. For joining the cross-piece to the barrel a hole is blown out

at O, as well as at *d*, and the heated ends having been put together the joint is worked uniform by rotation in a pointed flame as before. The short inner communicating tube is introduced at this stage by either of the two following processes:

The first and simplest way is to soften and enlarge the barrel of the plug and then form two small holes as shown in Fig. 35 (1) diametrically opposite each other. The

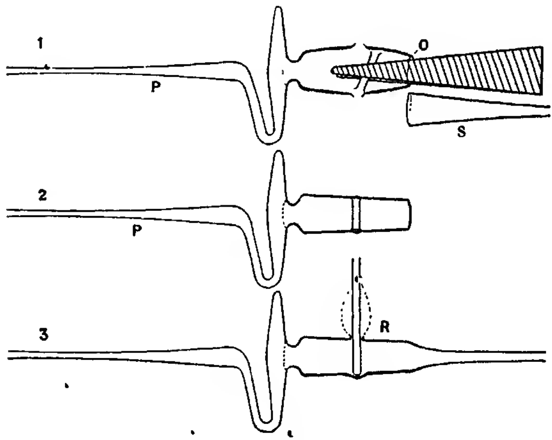


FIG. 35.

right spindle is now cut off temporarily, giving a fairly wide opening O. A short length of thick-walled tubing cut out of a waste spindle is now introduced through O by a pair of pincers as shown, and one end fused on over one of the holes. The cross-tube is gently pushed in vertical and the opposite side of the plug softened and collapsed on to the other end, care being taken that the hole comes into sealing contact all round the rim of the inner tube. Keeping this region hot by using a large

flame, the operator again fuses on the right spindle, S, and, blowing through it, softens, blows out, and pulls apart the whole of the plug, forming it into conical shape by spinning. The internal pressure of the blowing tends to close the holes, and hence they require to be periodically enlarged with a pin tool. The circular section for the stopper is best effected by softening and spinning against a flat tool applied horizontally until it has come down to the size of the template. The spindle S may now be drawn off and the end shaped down flat (2) by blowing through P.

The second method is to blow out a hole on the side of the plug, and through this opening introduce the closed end of a piece of narrow-bore tubing to form the cross-piece inside. After the closed end has been thoroughly fused into contact, the projecting cross-tube is softened round at R (3), Fig. 35, and blown out thin against the plug so as to come into sealing contact all round the edges of this hole. It is worked thereafter as before, and usually it is finished off with the ends of the cross-tube closed, so that they have to be drilled out after or during the grinding.

The grinding of the stopper to fit the socket offers no special difficulty if care has been taken in the beginning to give them a true conical shape and approximate equality by the use of templates as suggested before. The stopper may be ground inside the socket itself straightaway, especially if the stopper is solid, the hole across being drilled after a good fit has been obtained. But with a hollow stopper the definite position of the cross-tube sets a limit to the grinding, which is reached when the cross-tube comes opposite the two side tubes, and further grinding will have to be stopped whether a good fit has been obtained or not. Further, if the inequalities of section between the two are great, or if

there are prominent departures from a circular section or conical shape, a proper fit cannot be obtained by a grinding together of the two, since the tendency is to deform the shape of both the stopper and the socket. In such cases the commercial method will have to be resorted to as being the best.

Here the procedure is to grind the two parts separately in corresponding metal cones until equality in size is established between the two. Then the stopper is given

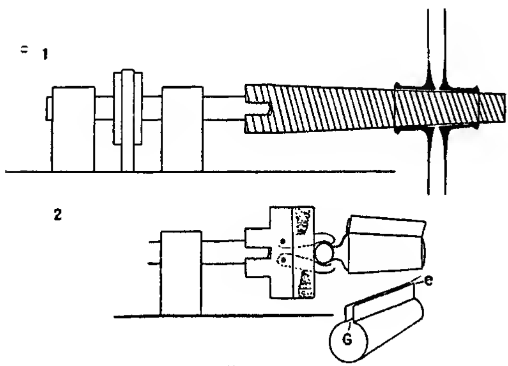


FIG. 36.

a final grinding in its socket by the use of very fine abrasive to give it a smoothing finish and perfect fit.

Since the taper of stop-cocks made in one works is very nearly the same irrespective of the size, a single conical rod of iron chucked in a crude lathe (Fig. 36) serves to grind out all the sockets to the same taper or angle, the size varying according to the distance to which they enter along the conical rod. A few strips of sheet iron, $\frac{1}{16}$ inch to $\frac{1}{32}$ inch thick, and about 2 inches wide, are bent to fit this grinding cone at various distances from the end, and they form the corresponding tools

to grind out the stoppers to the size and taper to fit the sockets. A little gap G of a millimetre left between the upturned ends e of the iron strip gives the stopper-grinding tool a small range of variation from one size to the next by the mere squeezing together of the two ends as the tool is pressed round the stopper, which runs in a lathe, its cross-arm being held between a pair of rubber cheeks on the chuck. By this method the grinding together of a stopper and socket to give perfect fit is only a matter of a few minutes if fine carborundum is used as the abrasive.

There is another very useful little device practised by some experts for giving a temporary support to a small piece that has to be worked or spun out in the flame. We have already seen how the barrel of the socket for the stop-cock was supported by a bent spindle that permitted

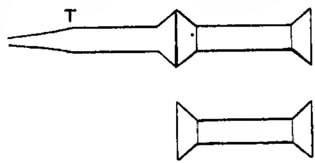


FIG. 37.

of rotary motion for spinning the second end. Suppose a glass spool of small dimensions is the object desired. Evidently a mark will be left if a bent spindle is used to support it by the middle, so this is out of the question for the present purpose. In such a case, the end of a small supporting tube T is first thickened and then spun out as shown in Fig. 37, and kept hot over an auxiliary flame. After one end of the spool has been spun out at the end of a normal spindle, the end of the supporting tube is lightly stuck on to it at a dull red heat, and then the spindle on the right side drawn off, the end enlarged and spun out to form the second flange for the spool. At the close of the operation a gentle knock on the spool severs it off

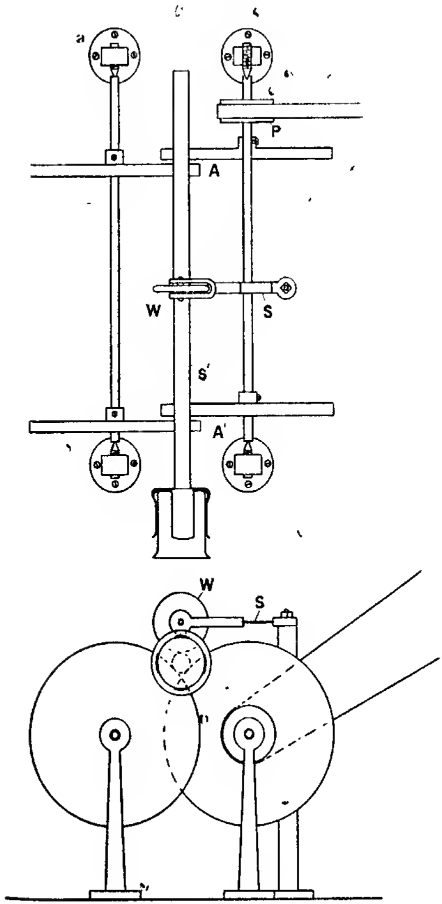


FIG. 38.

from the supporting tube, a slight warming of the joint momentarily in the flame being useful sometimes to make the spool come off the holder.

At the close of this section we may describe a very useful type of lathe arrangement largely used in glass works for producing spun glassware in quantities. Described simply, it consists in a pair of wheel bearings A and A′ on a pair of parallel axes suitably pivoted at their ends and kept in slow rotation by power through pulley P. The wheels permit of being adjusted along the axes and clamped in any position. A steadying wheel W on a springy swing arm S can be made to bear down on the rotating stem S′, which carries at its end in a suitable clamp the glassware, such as a beaker that requires its mouth to be enlarged by spinning. In the spinning of small work like conical ground joints or sockets for stop-cocks, the glass itself forms the stem S′, and the work is directly spun out at its end.

CHAPTER VII

COMMERCIAL METHODS FOR LABORATORY GLASSWARE

It is often of great interest to know the processes adopted for the manufacture of laboratory glassware on a commercial scale, and, moreover, such knowledge enables students in the laboratory to devise ways and means of overcoming special difficulties experienced by them in their glass work. It would be difficult, even if the information were available, to enter into the details of commercial practices which differ widely from place to place. All that we can hope to do is to indicate on broad lines the ways in which certain pieces of laboratory glassware are made.

Since many of these are bulky articles, requiring too much glass and of too unwieldly a size to be comfortably handled in a blowpipe flame, they are made directly at the glass works, where the necessary facilities exist. In general the arrangements for this kind of work are as follows:

A high degree of purity in the glass is essential, and hence the ingredients of the necessary purity are gradually introduced in small quantities into a covered fireclay crucible or melting-pot kept at a high temperature in the furnace. If this temperature is sufficiently high, the ingredients readily melt and mix thoroughly during the frothing that occurs on fusion. When this high temperature and consequent fluidity of the glass has been main-

tained for some time, the process of "fining" takes place, and the glass becomes comparatively free from bubbles of any large size. In this stage the glass is too mobile and hot to be gathered at the end of the iron tubes for work. It is then allowed to cool down to the working consistency at which quantities of it may readily be gathered at the end of the tubes. These are clean iron tubes about 4 feet in length and about half an inch in diameter, and have a slight trumpet-shaped enlargement at the end to give a better support for the glass, though at high temperatures the glass itself sticks quite fast on to the clean iron of the tube, so that large masses of glass can be gathered at the end of the pipe and handled without fear of its dropping off during the operations of blowing, spinning, and shaping of the glass.

It may be of interest to mention here a few of the natural forces on which the glass-blower depends to alter the shape of the blob of glass he has gathered out of the pot. It may be too hot and soft, and then he can cool it a little in water before starting work on it. It may not be symmetrical in shape, and he can make it so by rolling it gently over a flat sheet of iron. He can distend it to form a spherical bulb by blowing into the tube, and he can elongate this bulb into a cylinder by merely swinging the tube like a pendulum, when the combined actions of gravity and centrifugal force produce the desired effect. By merely rotating the tube rapidly about its axis he can bulge out the sides of the bulb by means of the centrifugal force acting on the plastic glass. He can reheat and soften the mass of glass periodically at the mouth of the pot, where a fierce heat exists. For spinning operations on the glass he sits on a sort of arm-chair provided with a pair of knife edges or rails over the arm-rests. On these he can roll the blowing tube with the left

hand and give the glass the rapid rotation it requires while the shaping or spinning tool is held against it by the right hand.

After this brief survey of the mode of work of the glass-blower at the factory, we may proceed to discuss in brief the procedure adopted for some particular specimens of laboratory glassware.

The primary article is the glass tube out of which so many other things are made in the laboratory as well as in the finishing shop of the glass works. To make a full length of glass tube at one stretch, a large quantity of glass has first to be gathered at the end of the blowing-tube. This can be done only in three or four successive stages, since the glass in the pot is too fluid to adhere to the tube in large masses at a time. After gathering an initial blob of as large a size as possible, it is blown out a little, made pear-shaped, and allowed to cool and gain in rigidity. It is then reintroduced into the pot and a fresh layer gathered all round this initial blob. When the requisite mass of glass has been collected by a repetition of this process, it is blown out into an elongated bulb whose size and thickness of walls are governed by the size of tube required to be formed out of it. It is a matter of considerable experience to be able to reproduce tubes of about the same size every time. At this stage an assistant who has collected a blob of glass at the end of his pipe sticks it on to the bottom of this bulb, and facing each other the two workers begin to walk backwards with the mass of glass stretched horizontally between their blowing-tubes. The rate at which the men recede from each other is again a matter of considerable experience, governing the ultimate size of the finished tube, both as regards its bore and thickness of walls. In general, for large tubes the men move back only slowly, just taking the sag of the glass between them,

while for narrow quill tubes they move away from each other at a good walking pace.

During this operation of drawing the tube horizontally it cools on the under side, owing to the current of cold air rising past it. To make the effects of this cooling uniform all round the tube, the glass is periodically rotated through the same angle simultaneously at both ends at a prearranged call signal. Boys with fans are also frequently employed to cool down quickly any portion of the glass that tends to get drawn out thinner or smaller than the rest of the tube. The tube as drawn out is laid on a wooden rack like a ladder, and the masses of glass at the ends having been cut off, the central region of uniform tubing is cut up into 6 or 8-foot lengths by the application of a pair of cold tongs, and the resulting bundle is taken straightway to be annealed.

In modern works it is usual to find glass tubes of all sizes drawn by semi-automatic and automatic processes. In the former the glass is gathered and shaped to the initial bulb as usual, and then drawn by machinery in a vertical tower while held between a fixed and a moving platform. In the latter, a cone of fireclay rotating at high speed draws a continuous ribbon of glass out of a tank furnace, and as the glass moves towards the point of the cone, a central jet of air blows it out to form a bulb or cylinder, which is drawn off between rollers at a steady rate.

The formation of a triangular section with white inlaid backing, as shown in Fig. 39 (1), for certain classes of tubing used largely in thermometry, is of some interest. The white backing is readily laid on between the successive gatherings of glass, and in the case of a clinical thermometer tube the gathering finally approximates to a blob about 4 inches in diameter, with a central hollow nearly an inch in diameter. Blowing in to form

this hollow in such a thick mass is done with the help of a rubber bulb stuck on to the end of the blowing-pipe, and squeezed by an assistant. By swinging, the mass is then elongated to form a cylinder about 3 inches in diameter, and after the outer layers of glass have been re-softened, it is pressed against an iron flat and the required shape of section given to the glass. The walls being thick and the glass a little cool and rigid, the procedure does not materially affect the section of the cylindrical central hollow. It is then drawn out as usual by hand, great care being taken to see that no twist is introduced in the glass.

Knowledge of these operations is useful as a guide for work in the laboratory, where short lengths of tubes for special purposes may be easily made out of any other size of tubing available. In fact, very often a short length of tube wider or narrower than the tube worked on may easily be formed out of the tube itself, and thus an unsightly joint saved.

The next article of interest is the test-tube of all sizes. In one works the lengths for the wider test-tubes are first cut out of tubing, a diamond being used to give a circular initial scratch inside. One edge of these tubes is then expanded out to form the mouth, and then the other end sealed and rounded. A special blowpipe, giving a very hot, pointed flame, is used for rapid work, and differs from the ordinary blowpipe in that the gas and air supply tubes are heated by a row of fine jets of burning gas.

Flasks, beakers, funnels, and bottles of all sizes are all blown into moulds, of special design, whose halves fit together so perfectly as to leave no trace of a wing or line of joint in the finished article. The interior of the moulds (nowadays made of metal) are faced with suitable greasy dressings that do not stick to hot glass,

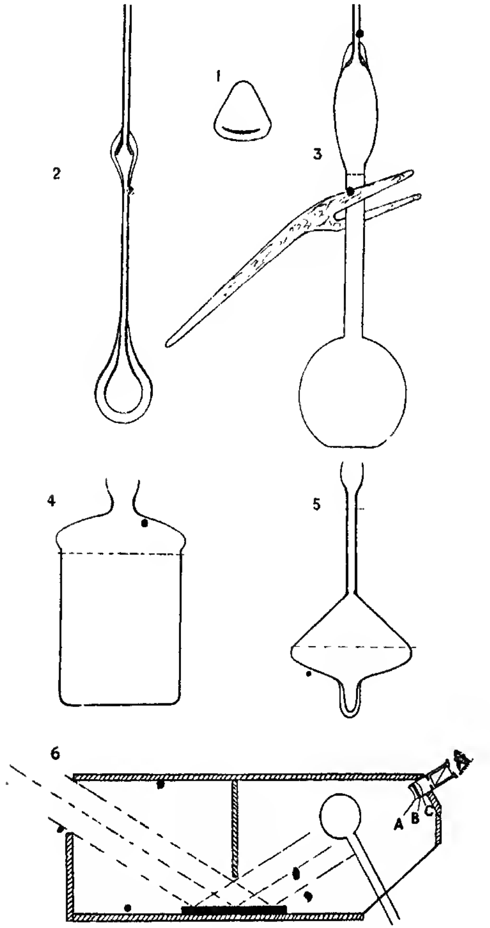


FIG. 39.

and they minimise to a great extent the inevitable marks left by the mould. The requisite quantity of glass gathered at the end of the blow-tube is first blown out a little, and then rolled on the edge of an iron flat, so as to distribute the mass of glass in such a way that when it is expanded by blowing into the mould the resulting thickness of wall is as uniform as possible throughout. For a flask an extra mass of glass has to be provided at the end, and then by a swing as the neck gets elongated (2) it is introduced into the mould (whose halves are closed around it by pressing a pedal) and blown, the work being rotated inside the mould until it is rigid. The blob of glass outside the mould is now blown out thin, and suspended by it the flask is taken out of the mould (3). At this stage an assistant applies the forked end of a wooden stick across the neck of the flask and by a twist breaks it off the iron blow-tube, and takes it straight to the annealing oven. The beakers and funnels present the appearances shown in Fig. 39 (4), (5) as they come out of the mould, and because of their dome covering they present but little resemblance to the finished article. These idle domes are cut off in the finishing shop, the method being to mount them on a rotating table and lead a crack, started by a diamond scratch, right round by a fine pointed flame as described on p. 15. The beaker pieces are then chucked on to the horizontal spinning lathe (p. 95), and their lips, heated by a row of about nine radial blowpipes, are opened out, and the spout also formed immediately by pressing down a softened region of the lip, the lip on either side of it being supported by two stationary rods. They are immediately sent to the reannealing oven to ease the strains resulting from these final finishing operations.

A large measuring-jar is another interesting laboratory article. Its cylindrical body is first blown in a mould

of the proper shape. It is then transferred to the shaper for chair work or spinning, by which the foot is attached and worked to shape. The glass for the foot is held in readiness by an assistant who sticks it on to the end of the cylinder as soon as it has cooled down enough to rotate rigidly at the end of the pipe. The excess of glass is pinched off, and the blob of soft glass left on the end of the cylinder is flattened and worked to shape with the aid of a few simple spinning tools. Before breaking off the cylinder from the pipe, an assistant sticks a small blob of glass (at the end of a blowing-pipe) to the bottom of the jar, and immediately by a cold iron the measuring cylinder is cracked off the holder and carried on the end of this " pontil " to the annealing oven, where a gentle knock suffices to sever it from the pontil.

We have often made reference to the necessity for annealing blown glassware before it is allowed to cool down to the atmospheric temperature. We may consider it in some detail at this stage, since its importance in the commercial factory is far more than in the laboratory, because of the larger sizes of glass, with thick walls, dealt with in these places. We may understand it better if we consider the necessity for the annealing, how it is done, and how its efficiency may readily be tested.

The necessity for annealing arises principally out of the peculiar thermal and physical properties of glass. It is a poor conductor of heat, and hence equalisation of temperature through a thickness of glass can take place only very slowly. It has an appreciable coefficient of expansion which is not of negligible magnitude. It cannot bear great strains of tension or compression without fracturing readily. Now, in the finishing off, say, of a cylindrical piece of glassware with thick walls, either at the laboratory or at the factory, the external surface begins to cool at once by radiation and by conduction

through the surrounding air, and tends to contract, while the inner surface as well as the mass of glass in the interior is shielded from such action. No harm is done so long as the mass of glass is plastic enough to yield to the forces brought about by the shrinkage of the outer envelope. But, as the glass cools down and becomes too hard to yield, a critical stage sets in and strains begin to develop. In the case considered they are readily seen to be of the nature of a tension on the inner surface and compression on the outer. The strains are thus set up mostly by the contraction of the inner layers during its cooling from the critical stage to that of the atmospheric temperature, and are thus proportional to this range of temperature. The more rapid the cooling and the thicker the glass, the bigger this range and hence the larger the strain. But if we keep the glass at or near the critical temperature for a time and allow the interior masses to cool down to this temperature, the whole mass is quite solid before the final cooling begins; and if this latter cooling also is conducted slowly, the resulting strains are of negligible magnitude. This process of maintaining the article at the critical temperature and then allowing it to cool slowly is called annealing.

An annealing oven in a glass works is a large brickwork chamber kept at a temperature a few degrees below the critical temperature at which glass begins to soften and deform under its own weight. All articles as soon as they are blown and before they have cooled down far below the critical temperature are placed in this oven, and the strains that were developing are eased away gradually during the initial rise of temperature. The oven when full of articles is closed up and allowed to cool by itself very gradually, a process which may occupy a week or more in the case of massive articles.

Such annealed articles often require further working

before they are made into the final form of laboratory apparatus. Thus the rough ends of flasks, measuring-jars, etc., and the domes of open articles such as funnels, beakers, etc., have all to be cut away along the dotted lines indicated in Fig. 39, and the ends smoothed out or slightly expanded by spinning. Such operations introduce strains of a minor order which are removed by rapidly passing the article through a reannealing oven. This is generally a long tunnel over 50 feet in length, in which iron trays carrying the articles can move along a pair of rails. About a quarter of the way down the tunnel a set of gas heaters is arranged to maintain this part of the tunnel at the annealing temperature. As each tray of glassware is pushed in, those in front of it are first gradually pushed into the hot zone and then gradually cooled as they move towards the other end, the time of passage of an article through the tunnel occupying generally two or three hours.

We may emphasise at this stage another point of importance in annealing. To ensure a finished product having no residual strains it is not essential that the very slow rate of cooling should be maintained from the critical temperature right down to that of the atmosphere. When the whole of the glass has set hard after its passage through the critical temperature, thin-walled laboratory articles at any rate may be cooled down fairly rapidly, the consequent residual strains disappearing as soon as the article attains the final uniform temperature of the atmosphere.

Table-blown glassware of the laboratory may also be given an annealing with advantage in a small annealing oven heated by a gas flame. A convenient brickwork chamber for the laboratory or small workshop is one about 2 feet square in area and about 1 foot deep. It should be provided with a small chimney outlet with a sliding

shutter, by which it may be closed down tight. The door of entry must also have a similar arrangement for closing the chamber when necessary. The articles to be annealed must necessarily be well finished, as otherwise they would fly to pieces during the heating up of the oven. They are assembled on an iron tray supported at a height of 6 inches from the floor. The heating gas-jets are most conveniently formed by a dozen millimetre holes in a ½-inch iron pipe connected to the gas mains through a control cock outside. After the articles have been assembled in the oven, the chamber is heated up slowly, and then the gas cut off and the oven shut down to cool.

The efficiency of these annealing operations in producing articles free from strain can easily be tested in polarised light, since such strains induce in glass double refraction of a type similar to that of crystalline media. When light polarised by its passage through a Nicol prism or otherwise is examined by another Nicol prism, a position can be found by rotating the latter at which the field of view is quite dark, and then the nicols are said to be crossed. If a double refracting medium like strained glass is now interposed between the two nicols, patches of light appear through the glass, and often these are separated from each other by broad dark crosses which may even be coloured in the case of seriously strained pieces of glass. Such glassware should never be used for any purpose, since it is likely to fly to pieces spontaneously at any time.

A very convenient strain viewer for the laboratory can easily be improvised by using a closed box fitted with nicols at either end, and an opening on the side through which any piece of glassware can be introduced and viewed between the nicols after the analysing nicol has been adjusted to give the darkest field of view. A strong illumination through the polarising nicol is

essential for the detection of the faint traces of strain noticeable in much glassware of daily use in the laboratory. For simplicity the polarising nicol may often be dispensed with, and the polarised illumination of the object obtained by reflecting the light of the sky on a sheet of black glass at a suitable inclination, as indicated in Fig. 39 (6). An ordinary piece of plate glass may also be used for polarising the light by reflection, but, since the light reflected by its bottom surface passes through its thickness of glass, it must be a piece free from strains within itself.

An interesting type of commercial instrument largely used in glass works for testing the efficiency of annealing is the Hilger strain viewer. A closed wooden box shutting off all extraneous illumination of the object is used, and the initial polarisation of the diffused light from an incandescent lamp is effected by reflection at a black glass plate as usual. In front of the analysing nicol a compound lens is interposed, which has a half-wave plate of mica (B) cemented between the concave (A) and convex (C) elements of the lens. The object of this complication is to give the field of view a uniform magenta tint, as it is then easier to locate the strained regions by their change in tint.

Apart from the bulky and large-sized articles made at the glass works directly from the furnace, there is a whole family of laboratory glassware made out of tubes. These are made in commercial quantities either at the finishing shop of the glass works, or in the glass-blowing department of the instrument makers. Considering the variety of designs into which these are made, and that the processes and procedures differ from place to place and from worker to worker, it is not possible to enter into their details here. The broad principles on which such table-blown glassware is made have already been discussed in detail with examples in the foregoing chapters,

and with their aid any one can easily set out the procedure suitable for any particular design of apparatus.

Simple pieces like pipettes and burettes are easily made by processes of straight-line joints, though some care and judgment are required to get them of the right dimensions for the particular capacity. Often in the case of a pipette, after the delivery tube has been joined to the short length of wider tube to form the middle reservoir, it is filled with alcohol or methylated spirit drawn out of a standard pipette, so that some idea may be formed of where the wider tube should be drawn off for joining on the narrower tube on the other side. These liquids are used in preference to water, as they dry easily and so cause no delay in proceeding with the work. Great attention is paid to such matters in devising the scheme of procedure for the production of articles in quantities. Thus one cannot afford to wait idle for the joint to cool before pouring in the liquid. Hence the glass-blower uses the interval in making a number of other pipettes, and does the approximate gauging for each later on as they cool down in turn. In the case of a burette, a stop-cock is joined on to the end of a suitable size of tubing, and in all such articles involving line joints (Fig. 10) the joint, being carefully located exactly at the angle of the shoulder, remains practically invisible.

We may emphasise at this stage the fact that in making all complicated glass apparatus the correct order of procedure previously settled upon facilitates the attainment of success without accidents and failures. This is a matter to which great attention must be paid before work is commenced on the piece, and the possibilities of failure well thought out and amply provided against, especially when parts that have to be made to dimensions are concerned. Any complicated or unwieldy apparatus

is usually made in parts, which are united together after being mounted on a temporary stand in their respective positions. This is essential to secure the correct alignment of the parts which adds so greatly to the elegance of the finished apparatus. It is then transferred over to its regular mount. Even the best finished of such articles leave enough clues in it to enable one to devise a procedure suitable for making up a similar article.

But there are some small lamp-blown articles, such as hollow stoppers for flasks, where very little of such traces are to be seen, and often when one has to replace one of these broken articles it is useful to know the procedure adopted in making it. So we will take a hollow stopper as a typical example, the various stages in the making being indicated in Fig. 40. A short standard piece (1), drawn out of thick-walled tubing, has a thick-walled constriction formed in it at one end, as shown at *x* (2). The glass between it and the spindle is then collected to form an elongated bulb, which is immediately pressed down flat between a pair of metal pincers. The neck *y* beyond the constriction is softened and blown out to round it, and then pressed together to give the flattened shape indicated in (3). The tubular glass beyond this neck is then collected together and drawn out a little to form the conical body for the stopper (4). The excess length is then melted off and the end blown flat against a plate, as in the case of giving a flat end to a tube (5). When the piece has cooled, or after its return from the annealing chamber, the spindle by which it was handled may be melted off, and before the pip cools down, if the flattened bulb is partly warmed, the expansion of the air inside blows out the pip into a nice rounded shape as indicated (6).

We have already touched upon the laboratory processes for conical ground joints, stop-cocks, and other articles

produced by spinning or shaping. Since considerable personal skill is required for this work it is costly in practice, and we may describe here the somewhat simpler commercial process, in which much less skill is required. The spinning lathe of Fig. 38 is used extensively for the

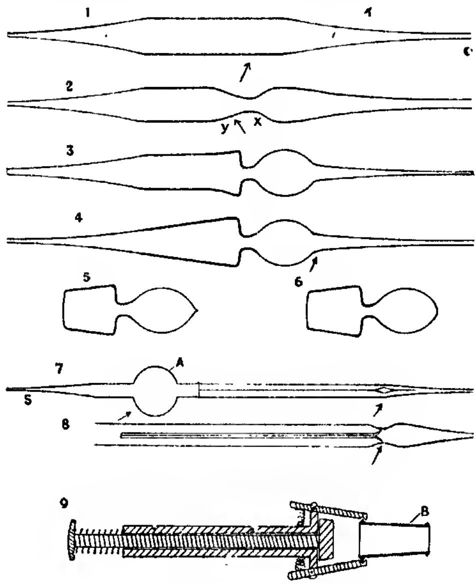


FIG. 40.

purpose, and the spinning out of conical ends for ground joints or other similar articles calls for no special comment. For the sockets of stop-cocks, the conical barrel with the thickened end is first formed at the end of a tube and spun to shape in the lathe, and the piece is then sent to be annealed. On its return from the oven the conical portion is cut away from the tube, and the piece being

held at the thickened end with a special form of spring holder sketched in Fig. 40 (9),[1] the other end is also spun out with the thickened edge, and the piece sent off again to be annealed. At this stage it presents the barrel appearance B indicated in Fig 40 (9). On its return from the annealing oven to the blowing table, the piece is handled as before by the spring holder, and the side tubes put on as described before without any difficulty. The piece is then sent away again to be annealed. This simpler process of successive stages is rendered possible by the thorough annealing that takes place between the successive stages. The stopper, nowadays always solid, offers no difficulty, since it is readily pressed in moulds directly at the furnace with or without the cross handle. The hollow cross handle when required is fitted on at the blowing table, as described before.

The thermometer is an important piece of laboratory glassware produced in commercial quantities, and the commercial and laboratory processes do not differ very much in practice. The process of blowing the bulb at the end of the fine capillary tube offers certain difficulties, and we have already discussed on p. 28 a simple way of forming an enlargement at the end of such a tube. In commercial practice a different procedure is used to exert an adjustable air pressure inside the tube while it is being heated. A bulb A is blown at the middle of a short piece of quill tube, and if one end of this tube is softened it can be stuck on to the warmed end of the capillary as shown in Fig. 40 (7), and a good temporary joint is the result. In this operation, since the end of the capillary has not been softened, the bore does not get choked at all. The outer end of the spindle S as well as the other end of the capillary are now sealed off, and air pressure can be

[1] In the actual holder there are three or more jaws, though only two are indicated in the figure.

exerted and maintained in the capillary by warming the air in the bulb, and any portion of the capillary may now be softened without fear of the passage being closed. If a region near the end is carefully softened it gets blown out into a bulb which may immediately be drawn out to form a cylindrical thin-walled tube. The cylindrical bulb for the thermometer may be formed of this by melting off the excess length and carefully blowing round the pip of glass left at this end. When comparatively large bulbs are required, the usual process is to cut off the cylindrical tube at its neck and join on to this enlarged end of the capillary a fresh tube of suitable thermometer glass. This is then blown out into a thin-walled bulb and drawn down to form the cylindrical bulb with specially thin walls. In the case of internally sealed thermometers, the fine thermometer stem is first prepared by this process to have an enlargement at one end, which is then internally sealed in the constriction drawn in a tube which forms the casing on the one side and bulb on the other, as indicated in Fig. 40 (8). For the production of spherical bulbs at the end of comparatively wide bore thermometer tubing, regular mouth-blowing is sometimes resorted to. It is somewhat hard work to exert the requisite air-pressure by the lungs, and special care has to be taken to keep the mouth dry and the tongue in a peculiar position so that the amount of moisture forced into the tube is a minimum. Templates of wood with holes in it are frequently used to gauge the size of the bulbs.

Another very interesting commercial process is machine glass-blowing, by which bottles and other laboratory articles are made nowadays in very large quantities. The bulbs for incandescent electric lights are also made by this process, and a single machine is capable of producing as many as 20,000 bulbs per day without human

assistance at any stage of the work. In the actual manufacture of these bulbs into lamps, processes of automatic machine-blowing are again used, though assisted at certain stages by the operators in charge of the machine. These are some of the modern processes by which scientific glassware is being manufactured in quantities, and though they are all very interesting the mechanical appliances involved are rather complicated, and space would not permit us to enter into their details here.

INDEX